CERES Cloud Properties, Ed4 and Beyond

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S. Bedka (SIST), R. Brown (QC), Y. Chen (clr props, test runs),
S. Gibson (graphics), E. Heckert (web, IG), G. Hong (night tau),
M. Khaiyer (val), R. Palikonda (GEO), B. Scarino (cal), R. Smith (web, NPP), D. Spangenberg (polar), C. Yost (phase)

SSAI, Hampton, VA, USA

P. W. Heck (retrieval algo)

CIMSS, U. Wisconsin, Madison, Wi, USA

CERES Science Team Meeting, Newport News, VA, 1-3 May 2012

Topics

- **Publications**
- **Terra/Aqua** – Ed2, Ed4 in process
- **NPP** – Ed1, June 2013
- **GEOSat** – Ed 1, June 2013
- **AVHRR** – Extending the CERES cloud record
- **Future work** – addressing new challenges

Update of CERES Cloud-related Papers since May 2012

Edition-2 related

Painemal, D., P. Minnis, J. K. Ayers, and L. O'Neill, 2012: GOES-10 microphysical retrievals in marine warm clouds: Multi-instrument validation and daytime cycle over the Southeast Pacific. *J. Geophys. Res.*, **117**, D06203, doi:10.1029/2012JD017822. .

Giannechinni, K., X. Dong, B. Xi., A. Kennedy, P. Minnis, and S. Kato, 2012: Comparison of CERES-MODIS Edition-2 cloud properties with CloudSat/CALIPSO and ground-based measurements at the DOE ARM North Slope of Alaska site. Submitted, *J. Geophys. Res.*

Yan, H., J. Huang, P. Minnis, Y. Yi, S. Sun-Mack, T. Wang, and T. Nakajima, 2012: Comparison of CERES-MODIS cloud microphysical properties with surface observations over the Loess Plateau. Submitted to *Remote Sens. Environ.*

Stubenrauch, C., W. B. Rossow, S. Kinne, S. Ackerman, G. Cesana, H. Chepfer, B. Getzewich, L. DiGirolamo, A. Guignard, A. Heidinger, B. Maddux, P. Menzel, P. Minnis, C. Pearl, S. Platnick, C. Poulsen, J. Riedi, S. Sun-Mack, A. Walther, D. Winker, S. Zeng, and G. Zhao, 2012: Assessment of global cloud datasets from satellites: Project and database initiated by the GEWEX Radiation Panel. Submitted, *Bull. Am. Meteorol. Soc.*

Edition-4/5 related

Hong, G., P. Minnis, D. R. Doelling, J. K. Ayers, and S. Sun-Mack, 2012: Estimated effective particle size of tropical deep convective clouds: A look-up table method using satellite measurements of brightness temperature difference between 3.7 and 11.0-µm bands. *J. Geophys. Res.,* **117**, D06207, doi:10.1029/2011JD016652.

Minnis, P., G. Hong, J. K. Ayers, William L. Smith, Jr., Christopher R. Yost, A. Heymsfield, G. M. Heymsfield, D. L. Hlavka, M. D. King, E. Korn, M. J. McGill, A. M. Thompson, L. Tian, P. Yang, and Henry Selkirk, 2012: Simulations of infrared radiances over a deep convective cloud system observed during TC4: Potential for enhancing nocturnal ice cloud retrievals. *Remote Sens.*, **4**(10), 3022-3054, doi:10.3390/rs4103022.

Update of CERES Cloud-related Papers, etc.

Edition-4 related

Doelling, D. R., B. R. Scarino, D. Morstad, A. Gopalan, R. Bhatt, C. Lukashin, and P. Minnis, 2012: The calibration of visible imagers using operational hyperspectral SCIAMACHY radiances. Submitted, *IEEE Trans. Geosci. Remote Sens.*

Sun-Mack, S., P. Minnis, Y. Chen, S. Kato, Y. Yi, S. Gibson, P. W. Heck, and D. Winker, 2012: Global cloudy boundary layer lapse rates determined from CALIPSO and MODIS data. Submitted, *J. Appl. Meteorol. Climatol.*

Conferences

Scarino, B., D. R. Doelling, D. L. Morstad, R. Bhatt, C. Lukashin, and P. Minnis, 2012: Using SCHIAMACHY to improve corrections for spectral and differences when transferring calibration between visible sensors. *Proc. SPIE Conf. 8510, Earth Observing Systems XVII*, San Diego, CA, 13-16 August, 8150-25.

Bedka, K. R. Palikonda, and P. Minnis, 2012: A CERES-consistent cloud climate record from AVHRR data. *4th WCRP Intl. Conf. Reanalyses*, Silver Spring, MD, 7-11 May.

Trepte, Q., P. Minnis, D. Winker, S. Rodier, and S. Sun-Mack, 2012: A comparison of cloud detection between CERES-Ed4 cloud mask and CALIPSO vertical feature mask. C*ALIPSO, CloudSat, EarthCARE Joint Workshop, The Role of Clouds and Aerosols in Weather and Climate*, Paris, France, 18-22 June.

Painemal, D., P. Minnis, K. Ayers, and L. O'Neill, 2012: Diurnal cycle in marine stratocumulus clouds over the Southeast Pacific inferred from GOES-10 satellite. *16th Intl. Conf. Clouds Precip.*, Leipzig, Germany, 30 July – 3 August, P.2-36.

Chang, F.-L., P. Minnis, N. Loeb, and S. Sun-Mack, 2012: Introduction to CERES multilayer cloud properties. *2012 Intl. Radiation Symp.*, Berlin, Germany, 6-10 August, IRS2012-541.

Hong, G., P. Minnis, W. L. Smith, Jr., S. Sun-Mack, J. K. Ayers, C. R. Yost, and Y. Chen, 2012: Non-opaque and opaque ice cloud properties form infrared radiances at 3.7, 6.7, 11.0, and 12.0 µm. *2012 Intl. Radiation Symp.*, Berlin, Germany, 6-10 August, IRS2012-491.

Heck, P., P. Minnis, S. Sun-Mack, Q. Trepte, F.-L. Chang, Y. Yi, R. Arduini, R. Smith, S. Gibson, R. Brown, and E. Heckert, 2012: Cloud properties from CERES Edition 4. *2012 Intl. Radiation Symp.*, Berlin, Germany, 6-10 August, IRS2012-555.

Sun-Mack, S., P. Minnis, Q. Trepte, Y. Chen, F.-L. Chang, Y. Yi, R. Arduini, R. Smith, S. Gibson, R. Brown, E. Heckert, and P. Heck, 2012: Cloud properties from CERES Edition 4. *2012 EUMETSAT Meteor. Sat. Conf.,* Sopot, Poland, 3 – 7 Sept.

Cloud Parameters in CERES Edition 2

Cloud Mask, Phase
Optical Depth, IR emissivity
Effective Radius/Diameter
Liquid/Ice Water Path
Cloud Effective Temperature
Cloud Top/ Bottom Pressure
Cloud Effective Pressure
Cloud Effective Height
Clear-sky Temperature

All data only available in SSF or 1° averages

New Cloud Parameters in CERES Edition 4

New Size Retrievals
Water droplet eff radius (1.24 μm)
Ice effective radius (1.24 μm)
Water droplet eff radius (2.1 μm)
Ice effective radius (2.1 μm)

CO2 Slicing
Cloud Top Pressure
Cloud Top Temperature
Cloud Top Height
IR Emissivity

Multilayer Cloud Retrieval	(Ice Over Water)
Multilayer Identification	
Upper Layer (Ice Clouds)	Lower Layer (Water Clouds)
Cloud Top Pressure	Cloud Top Pressure
Cloud Top Temperature	Cloud Top Temperature
Cloud Top Height	Cloud Top Height
Cloud Visible Optical Depth	Cloud Visible Optical Depth
Ice Effective Radius (3.7 μm)	Water Droplet Radius (3.7 μm)
Ice Effective Radius (2.1 μm)	Water Droplet Radius (2.1 μm)

All data available in SSF, 1° averages, & at pixel level

MODIS Processing Status

- Ed2 processing
  - *Aqua: through April 2012, will continue until ED4 ADMs completed*
  - *Terra: through April 2012, will continue until Ed4 ADMs completed*
  - *No more MODIS Collection 5 after Dec 2012, Collection 6 has begun*

- Ed4 delivered in July: known as Beta-1 Ed4 based on Coll. 5 data
  - *Aqua: November 2003*
  - *Terra: up to November 2002*

MODIS New Delivery

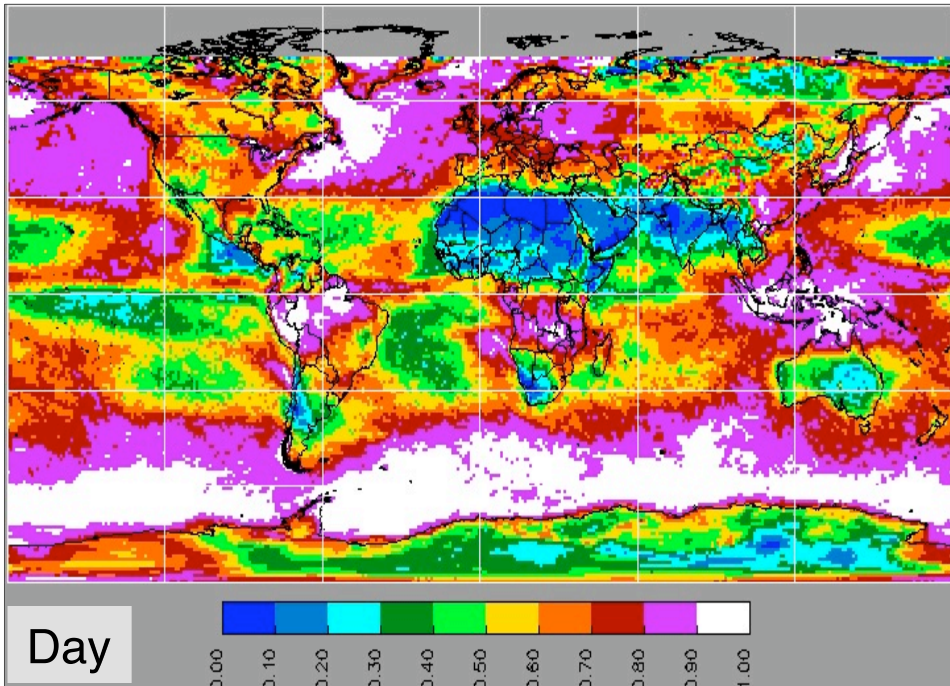
- Polar discontinuity in cloud fraction is negligible

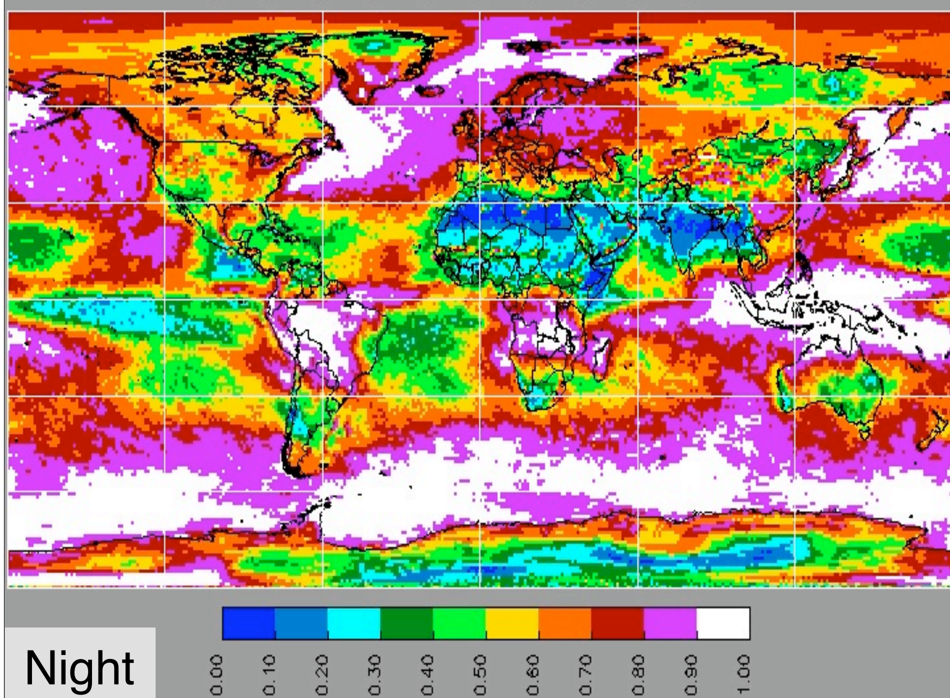
- Overestimation of polar clouds diminished

  - reduced BTD3.7-11 noise
  - recalibrated T3.7 for Terra
    - used data from every year
  - use graduated polar mask

- CO2 code input errors corrected

  - much improved, multilayer fraction





Total Cloud Fraction: CERES Ed 4 Beta 1 Winter 2000/2001

- Polar line minimally evident at 50°N during day, gone at night
  - other years, not evident at all
- Mean daytime: 65.1%
- Mean nighttime: 68.4%

Global Cloud Fraction Comparison
January and July 2008

	January Day	July Day	January Night	July Night
Beta-1 Aqua Ed4	2003 0.649	2002 0.647	2003 0.684	2002 0.678
Beta-1 Terra Ed4	2001 0.642	2001 0.637	2001 0.667	2001 0.674
Aqua Ed2	0.611	0.644	0.604	0.580
LaRC AVHRR	0.638	0.671	0.680	0.667
MODIS-ST	0.682	0.687	0.701	0.686
CALIPSO No 80km	**0.699**	**0.694**	**0.753**	**0.715**

- Total cloud cover has risen by 0.04 – 0.09
- Aqua & Terra more consistent than Ed2
- Day-night more consistent

Low Cloud Heights

- Ed2 used 7.1 K/km lapse rate anchored to surface to assign cloud height below 700 hPa

  - Minnis et al. (2011)

- Ed3 used zonal mean lapse rate based on MODIS-CALIPSO data

  - Minnis et al. (2010)

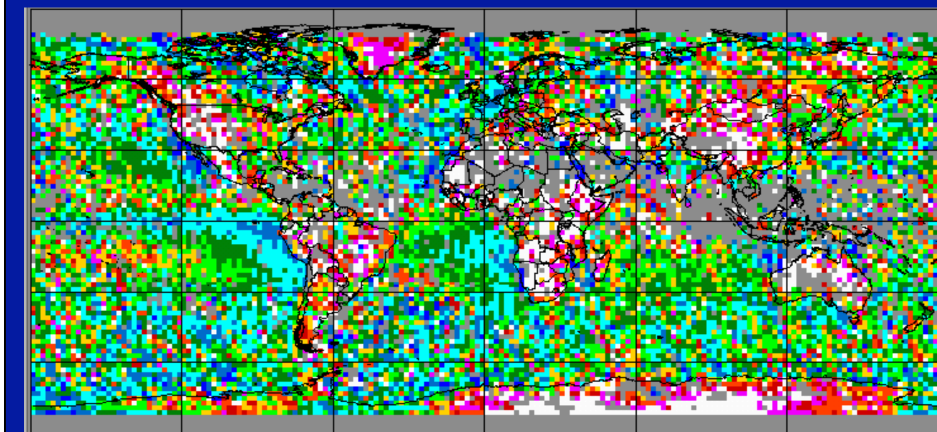
- Ed4 uses regional lapse rates based on MODIS-CALIPSO data

  - Sun-Mack et al. (2012)

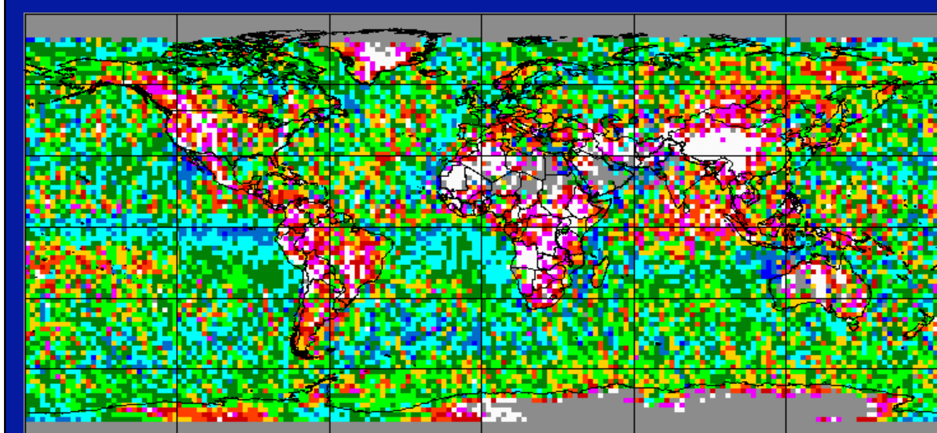
2007 10 day, single layer (CALIPSO), water clouds

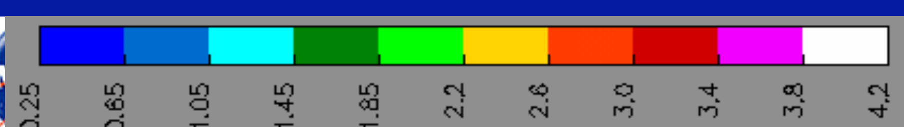
Cloud Top Height (km)

CALIPSO

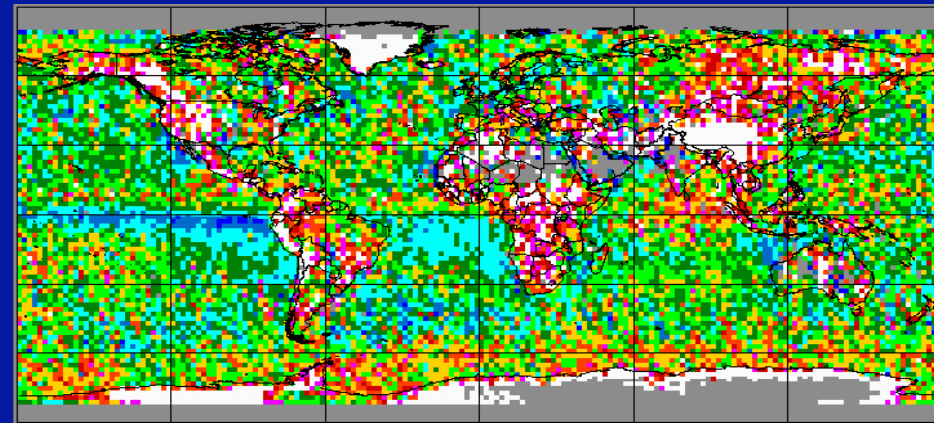


Map lapse rate

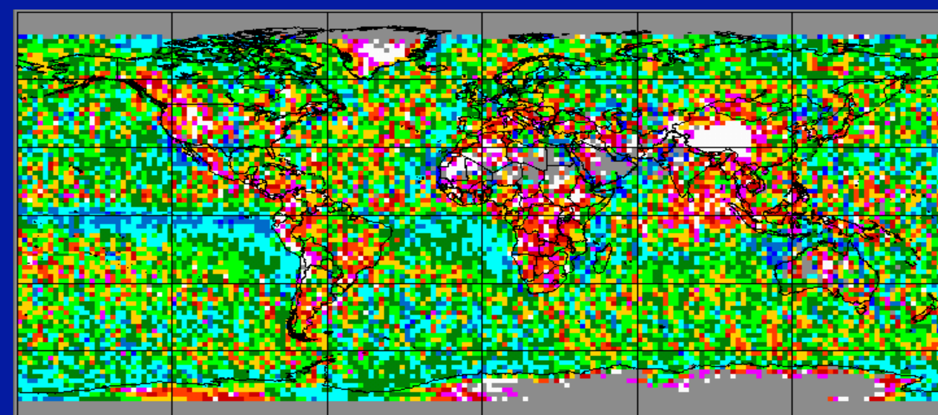




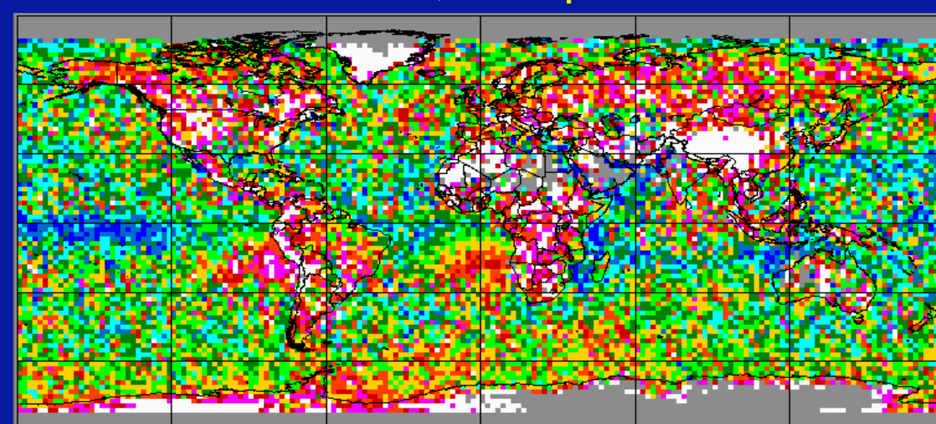
Zonal lapse rate



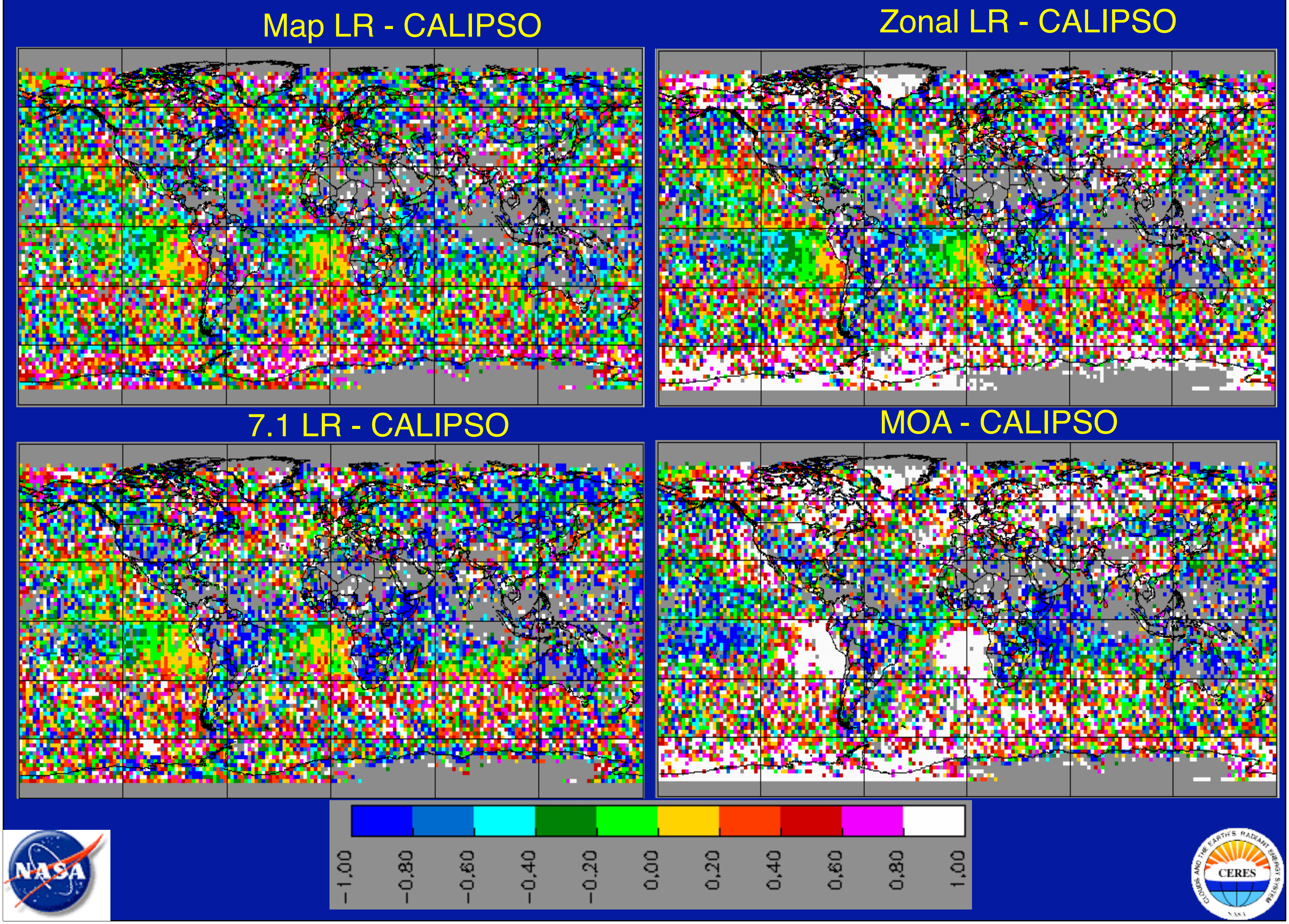
7.1 lapse rate



MOA, no lapse rate

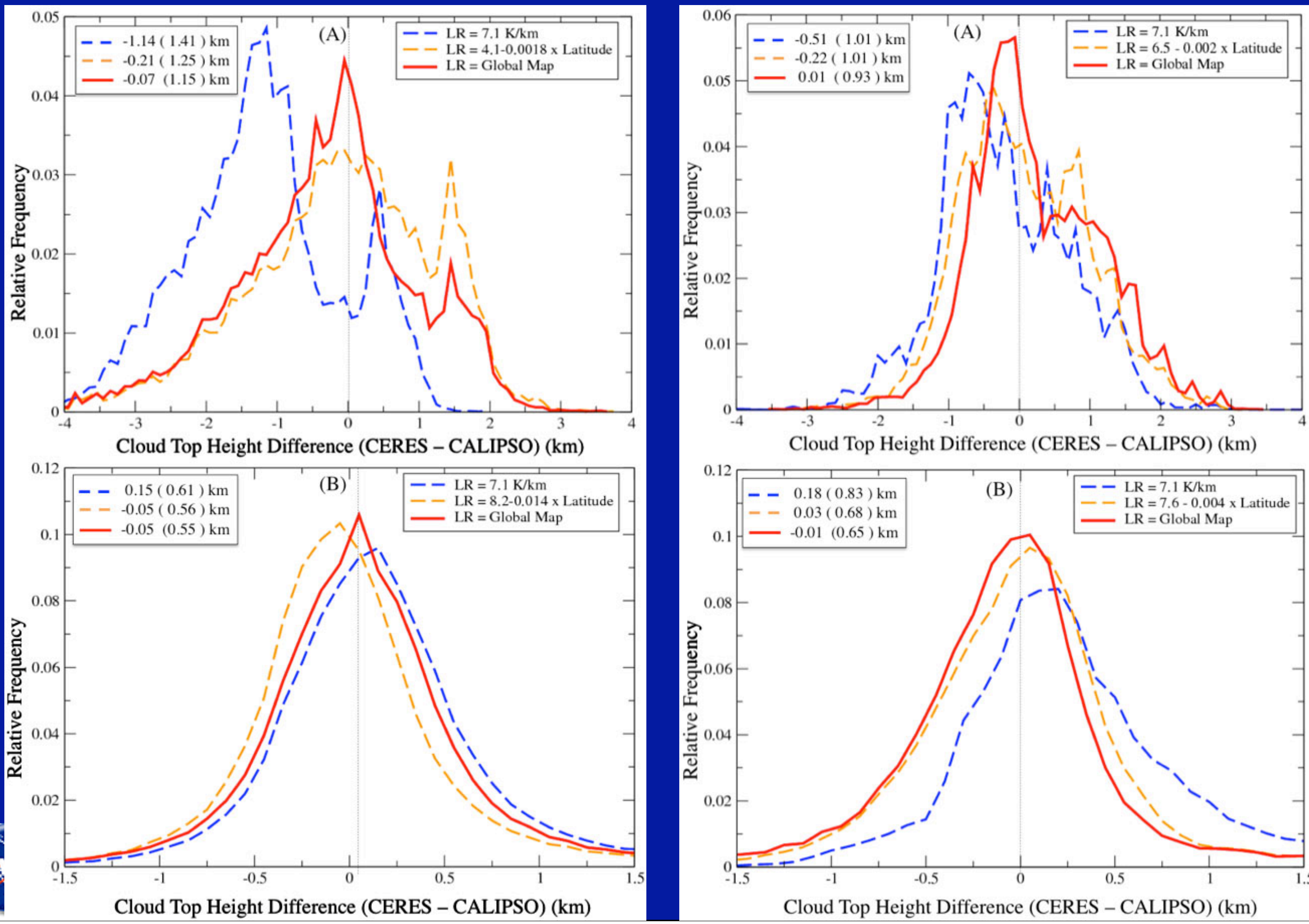


Cloud Top Height Difference (km), 2007 10, ATrain



Single-layer Low Cloud Height Differences, December 2007
CERES - CALIPSO

Day | Night



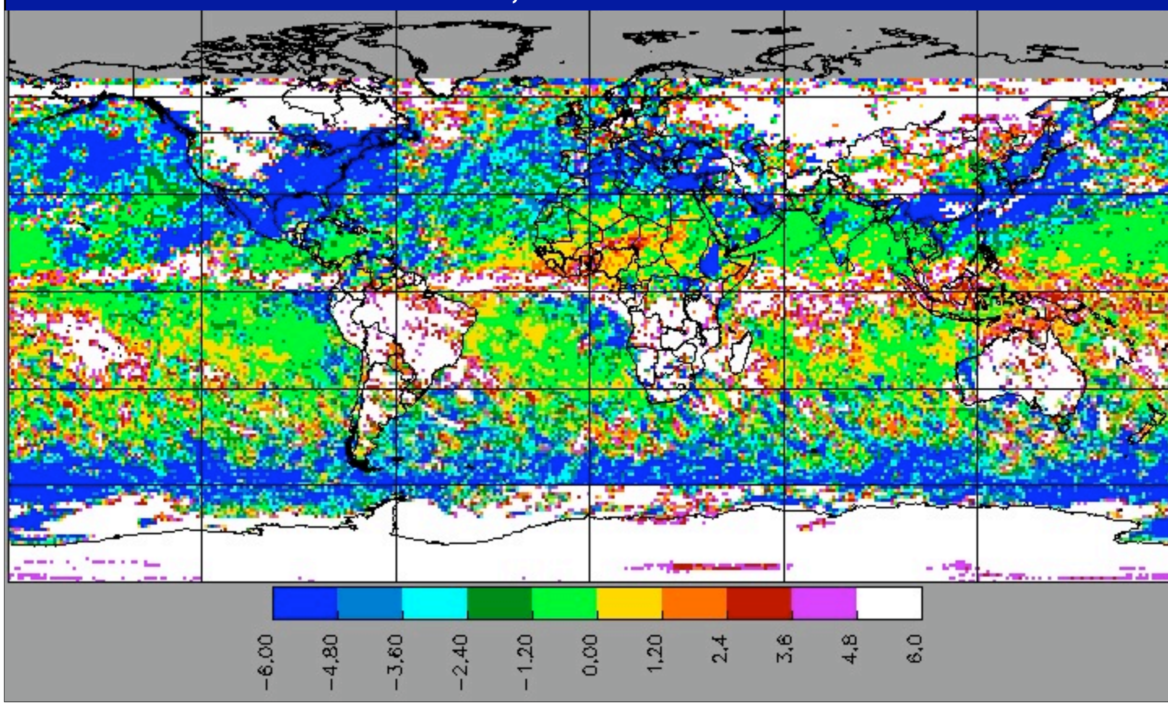
Ed2 to Ed4 Optical Depth Changes

---- A number of changes impact cloud optical depth

- Correct ozone absorption will decrease COD
- New *cloud retrievals over snow will increase COD*

    - Aqua Ed2 biased low
    - T & A Ed2 threw out many large COD clouds

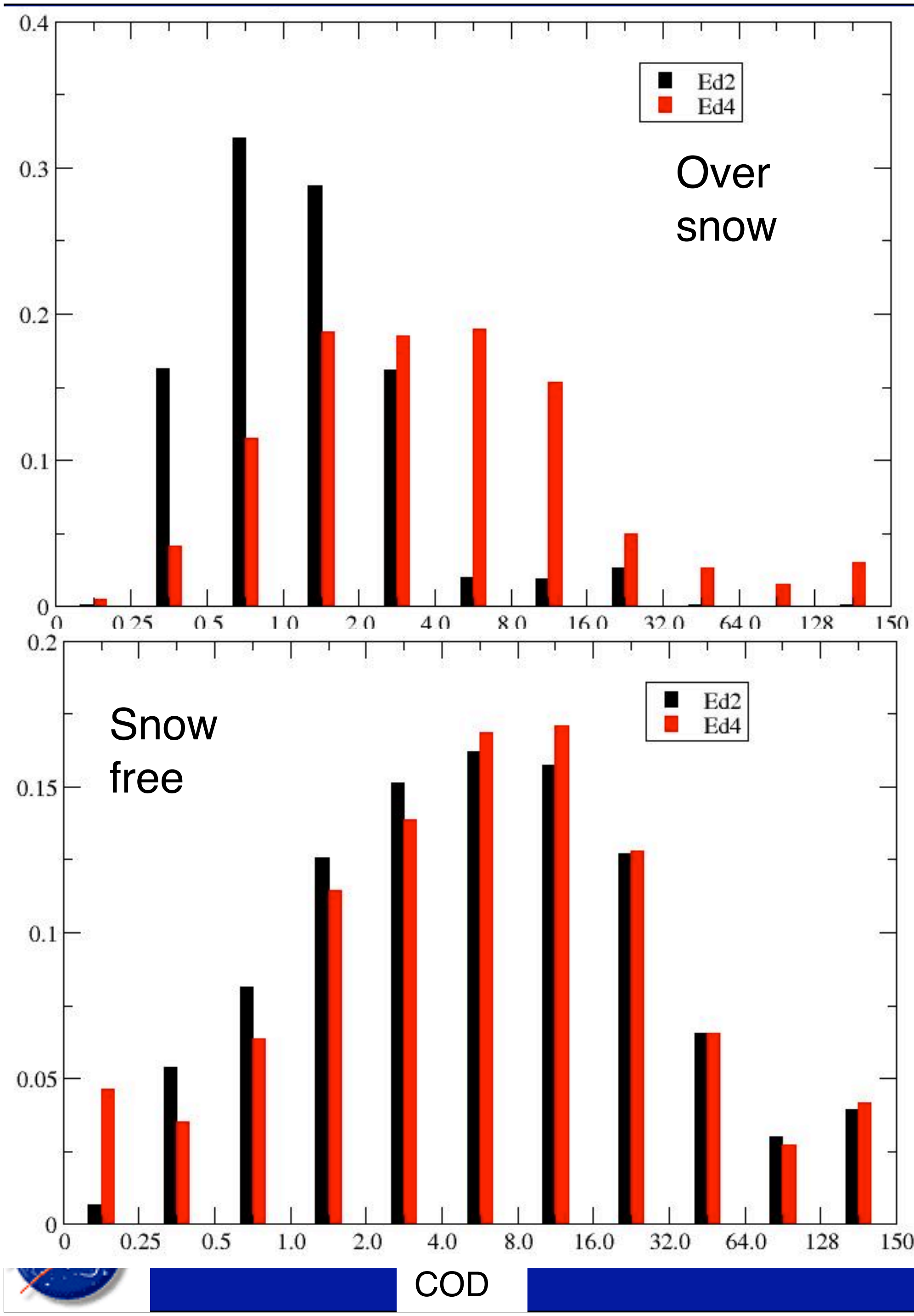
- Detection of optically thin cirrus with 1.38 μm will decrease ice COD
    - assume a temperature and Re, perform IR retrieval
- Use of new rough ice crystal models can raise or lower COD
- Max COD =150, was 128



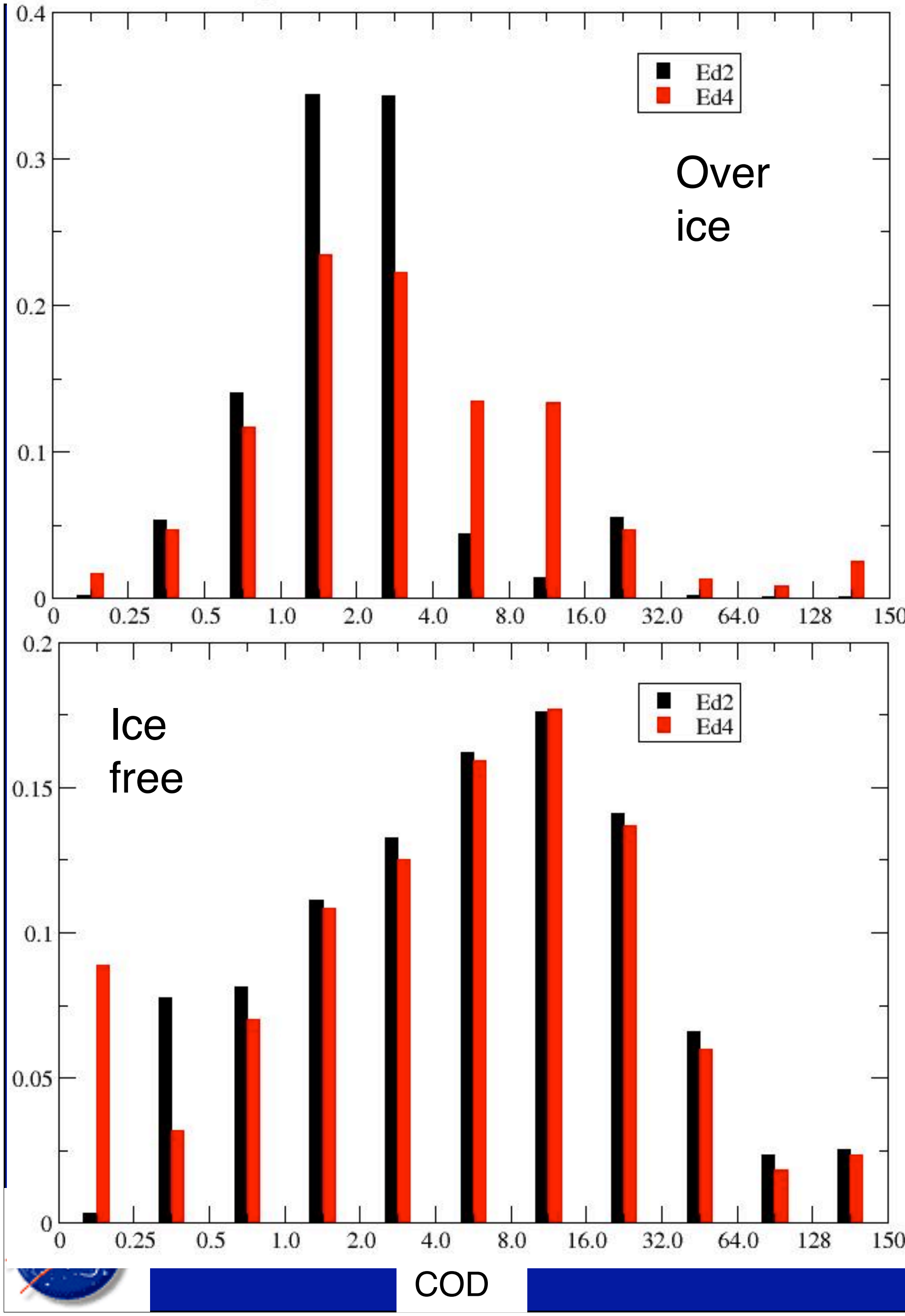
Ed4 - Ed2 COD

- COD rose in snow areas
- COD rose in deep convective areas
- decreased in midlatitudes
- decreased slightly in subtropics

Cloud Optical Depth Distributions
Ice Clouds over Land
Aqua, January 2007, Day

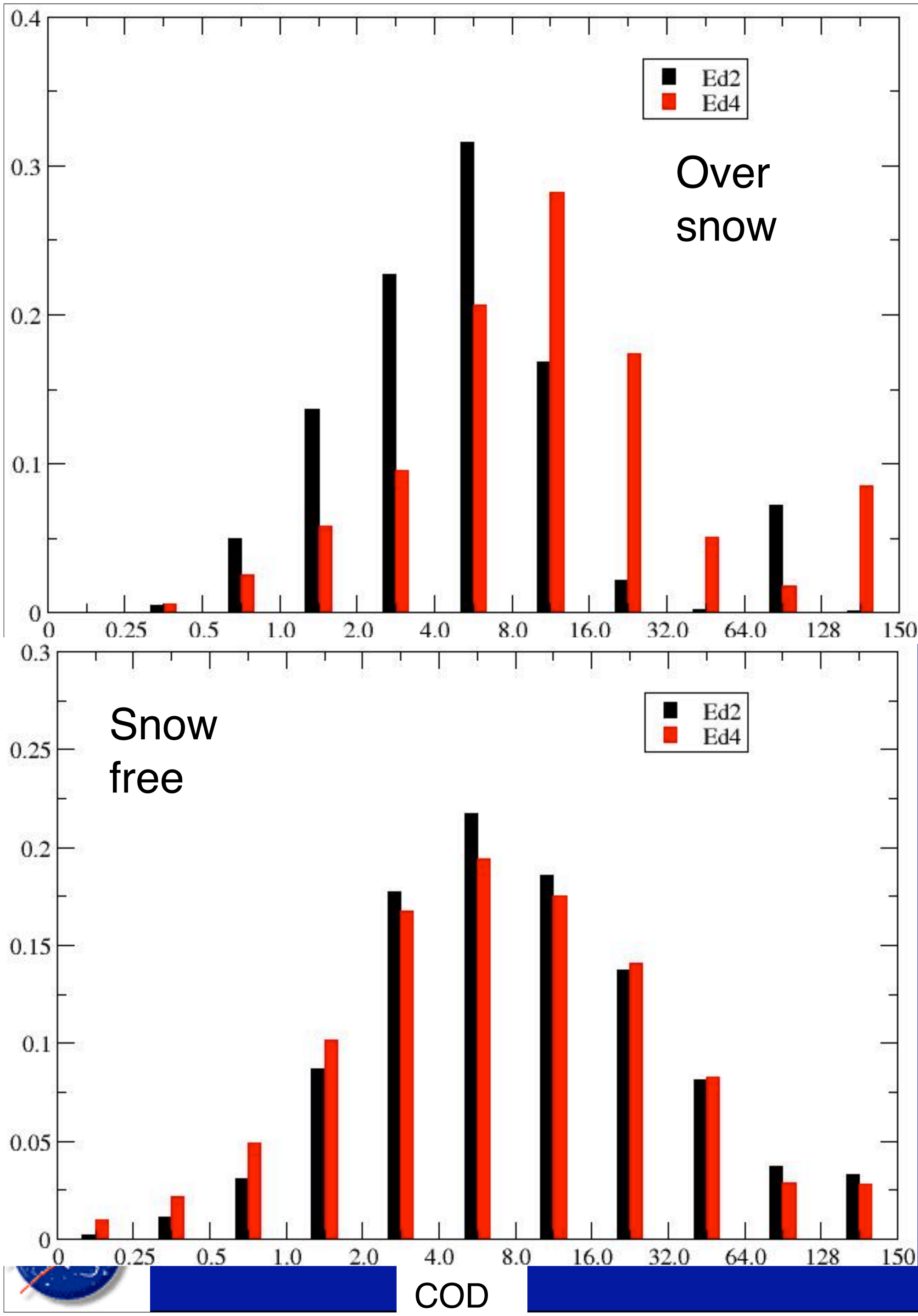


- Ed2 used 2.13-μm channel, barely sensitive to COD changes for COD > 8
- Ed 4 uses 1.24 μm, distribution over snow closer to that observed in snow free conditions
- Very thin clouds increased fivefold over snow free land
- Similar results for Terra



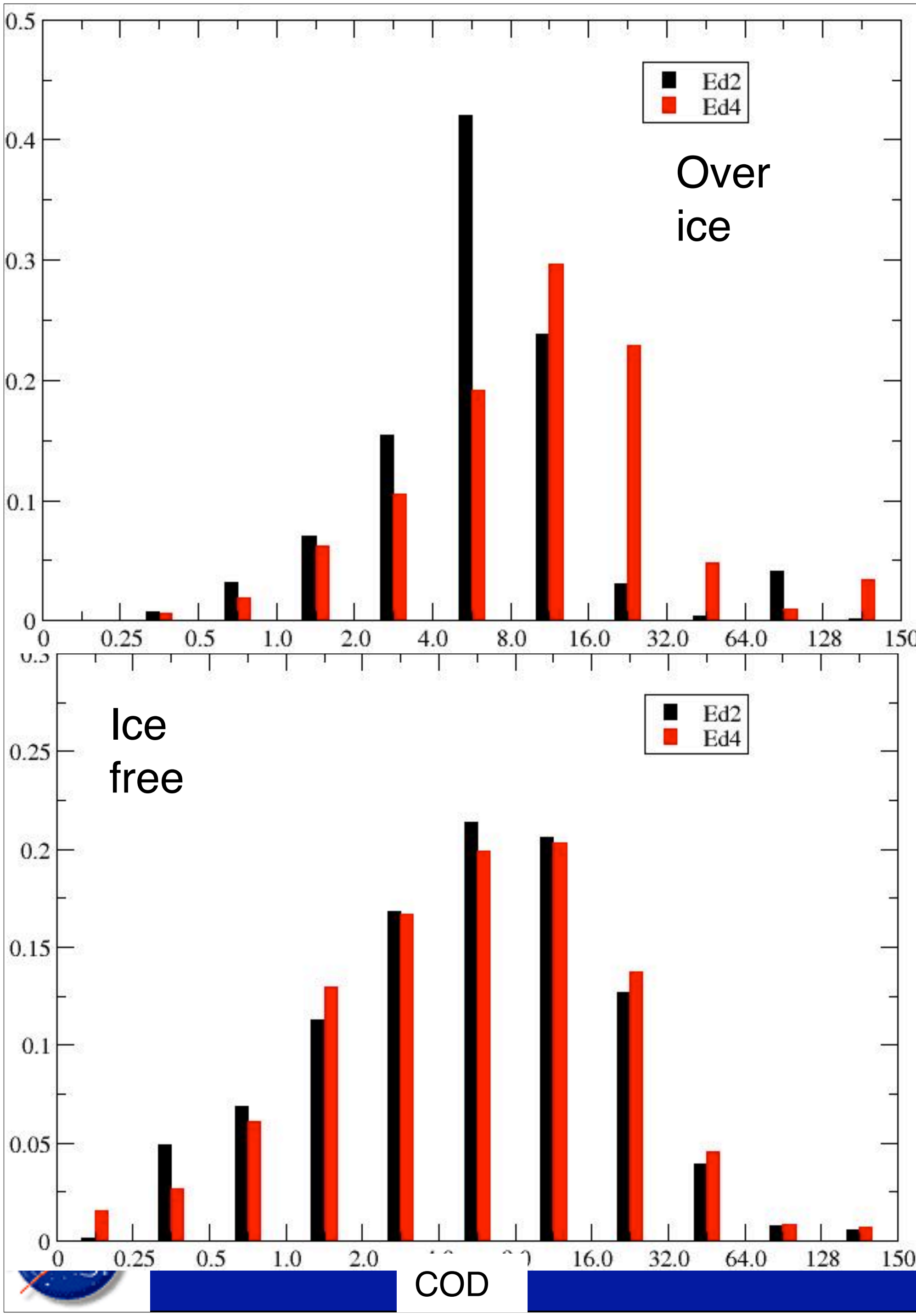
Cloud Optical Depth Distributions
Ice Clouds over Ocean
Aqua, January 2007, Day

- Ed2 used 2.13-μm channel, barely sensitive to COD changes for COD > 8
- Ed 4 uses 1.24 μm, distribution has fewer large COD over ocean ice than seen over land
  - still > Ed2
- Very thin clouds increased tenfold over ice free water
  - 1.38-μm detection easier over water?
- Similar results for Terra



Cloud Optical Depth Distributions
Water Clouds over Land
Aqua, January 2007, Day

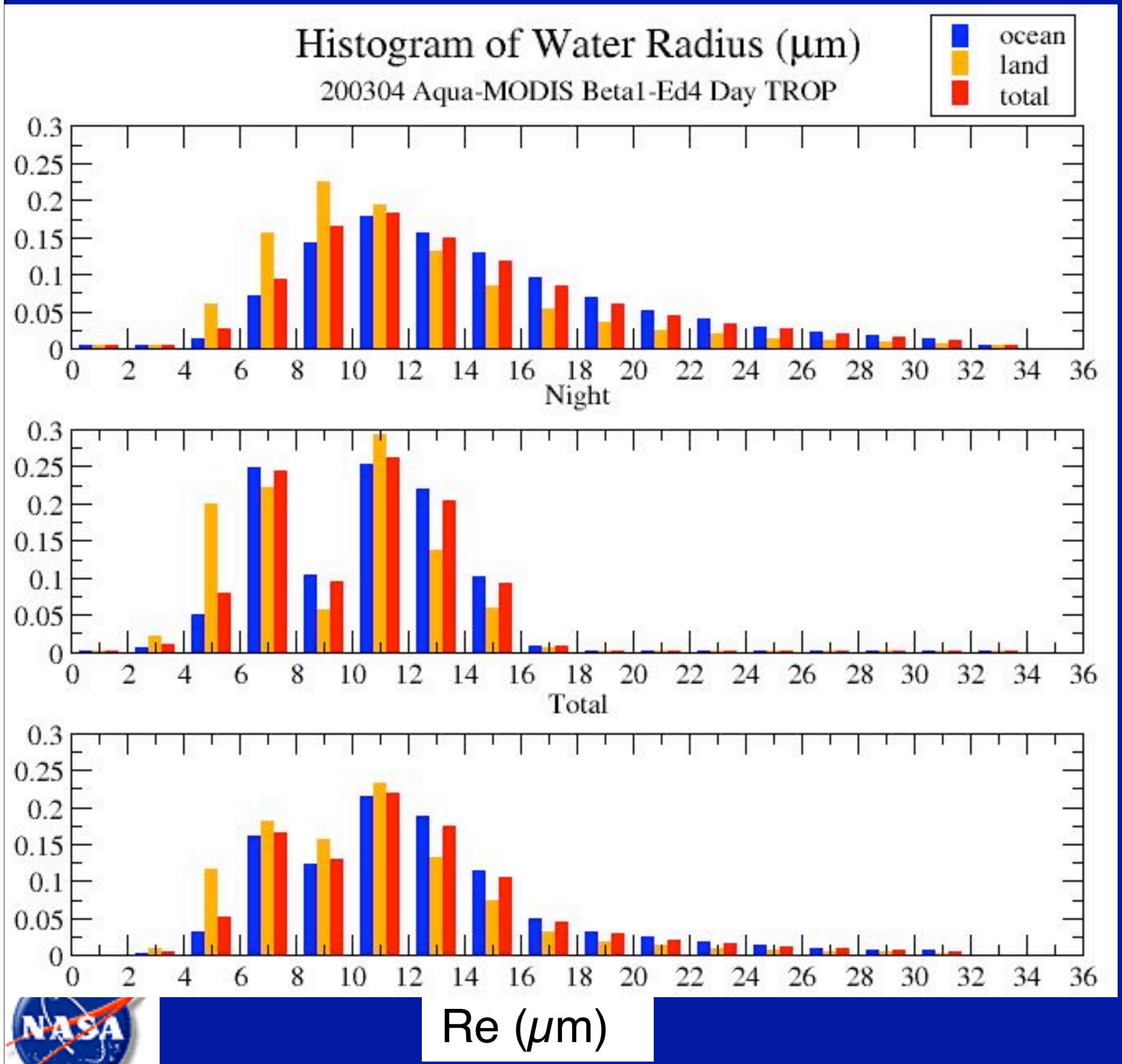
- Ed2 used 2.13-μm channel, barely sensitive to COD changes for COD > 16
- Ed 4 uses 1.24 μm, more large CODs
- More thin clouds over snow free land
  - *Ed4 detects more small Cu*
- Similar results for Terra



Cloud Optical Depth Distributions
Water Clouds over Ocean
Aqua, January 2007, Day

- Ed2 used 2.13-μm channel, barely sensitive to COD changes for COD > 8
- Ed 4 uses 1.24 μm, impact similar to that over land
- Very thin clouds increased tenfold over ice free water
  - *lost some in 0.25 – 0.5 range*
  - *some thin low clouds are aerosols*
    - *need further examination*

Cloud 3.8-μm Droplet Radii Distributions, Water Clouds over Tropics
Aqua, April 2007, Day



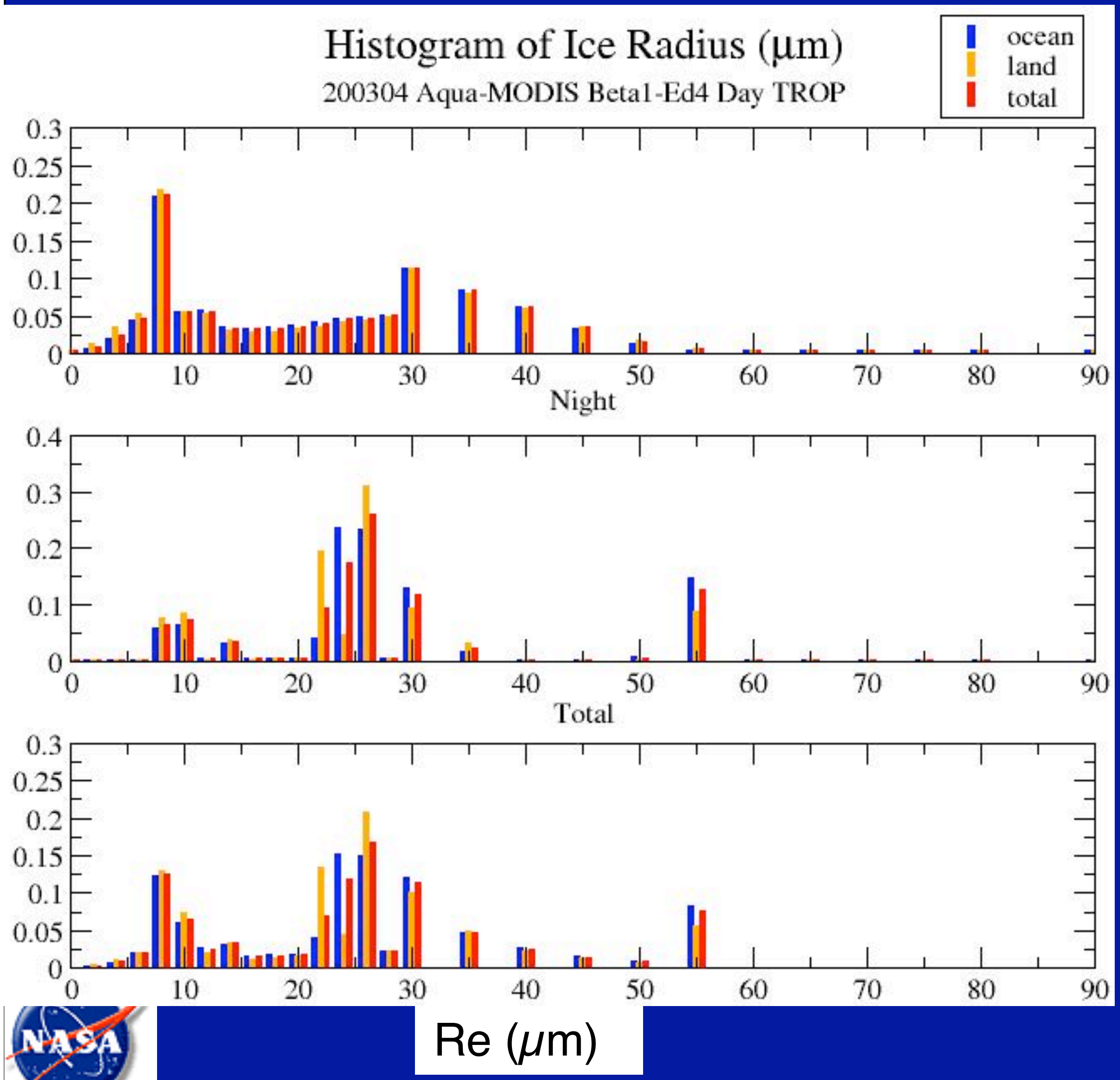
- Re over land smaller than over ocean, smooth function during day

- Default values used often during night, variation due to optically thin clouds

- Night distorts the total distribution

- *Use day results*
  - *- nonpolar mean*
    - *land = 11.8 μm*
    - *ocean = 14.4 μm*
  - *- polar mean*
    - *land = 13.8 μm*
    - *ocean = 12.9 μm*

Cloud 3.8-μm Droplet Radii Distributions, Ice Clouds over Tropics
Aqua, April 2007, Day



- Re over land and ocean similar, peak at 9 μm due mostly to new thin clouds and use of vis-ir method for some cases where fit to 3.8-μm models cannot be found (discontinuity at 30 μm due to discretization error in bin averaging)

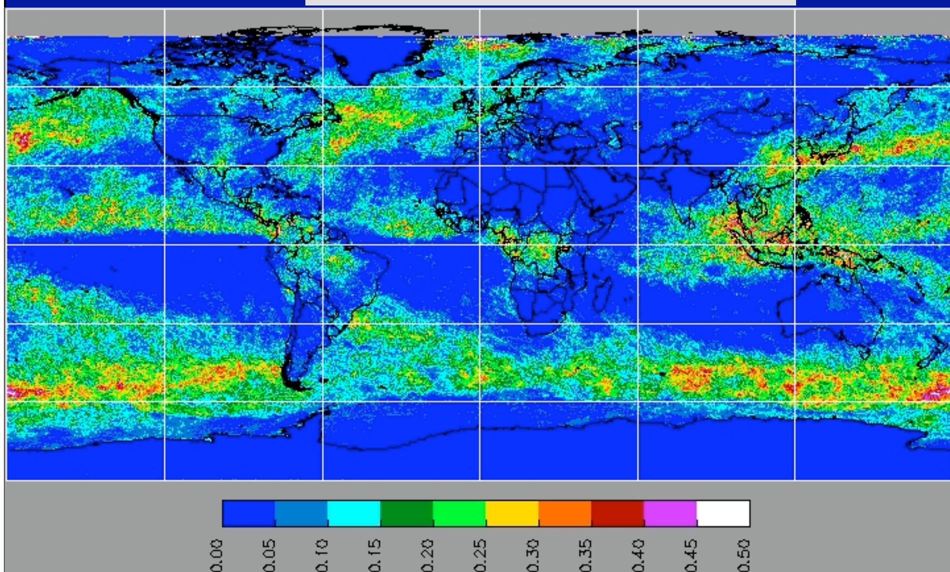
- Default values used often during night, variation due to optically thin clouds

- Night distorts the total distribution

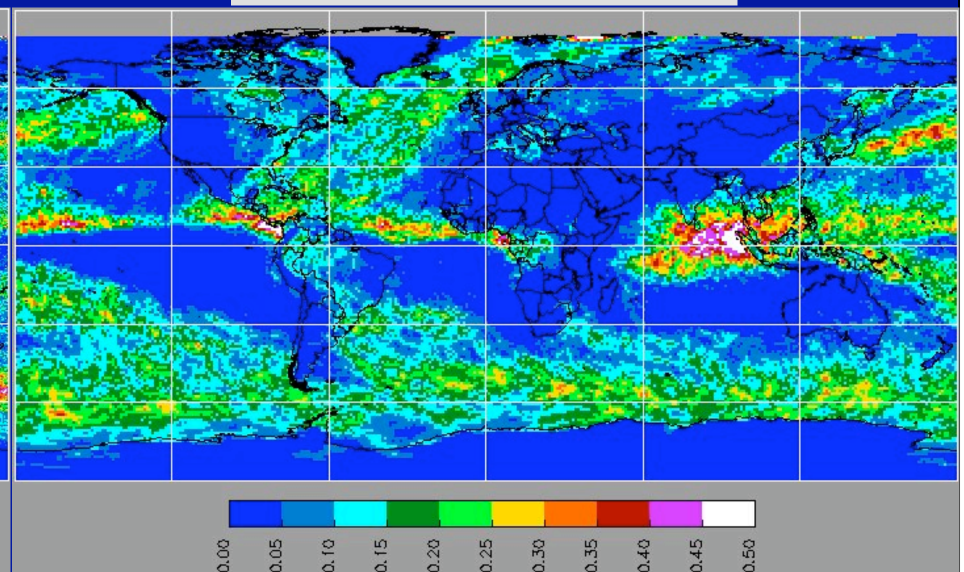
- *Nonpolar mean = 25 μm*

Daytime Multilayered Cloud Amounts, Edition 4
October

Ed 4 – del3, 2001



Ed 4 – Beta 1, 2007



- Final delivery picking up more in tropics, less in southern midlatitudes
- Chang talk on Thursday will provide details on Ed4 multi-layered clouds

MODIS Edition 4 Tasks Ahead

- Continue validation
  - *see B. Xi & S. Sun-Mack talks*
  - *other ground site and satellite comparisons*

- Complete Ed-4 documentation

- Determine differences in Coll 6 vs CERES-altered Coll 5 data
  - *use overlapped months to see if calibration problems disappeared*
  - *adjust codes as needed to smoothly use Coll 6*
  - *perform repeat cross calibration*

- Refine techniques when possible
  - *respond to feedback from downstream*

- Continue processing

NPP VIIRS

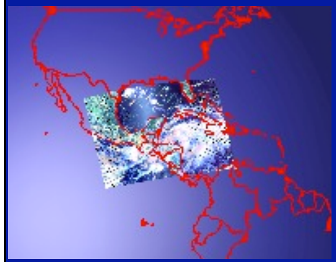
- CERES-MODIS Cloud Algorithms Adapted to NPP VIIRS Data

CERES Ed4-Lite

- no WV or CO2 channels
    - *diminished thin cloud height info*
    - *reduced polar night mask accuracy*
    - *no VIS/CO2-based multi-layer cloud retrievals*
- 1.24, 2.25 μm channels available =>
    - *consistent retrievals over snow*
    - *multispectral particle sizes*
- higher pixel density, resolution ~constant with VZA

- Problems with calibration apparently resolved, but
    - VIIRS data have a new format
        - *CWG working on a reader*
    - performed initial analyses with old-format VIIRS data

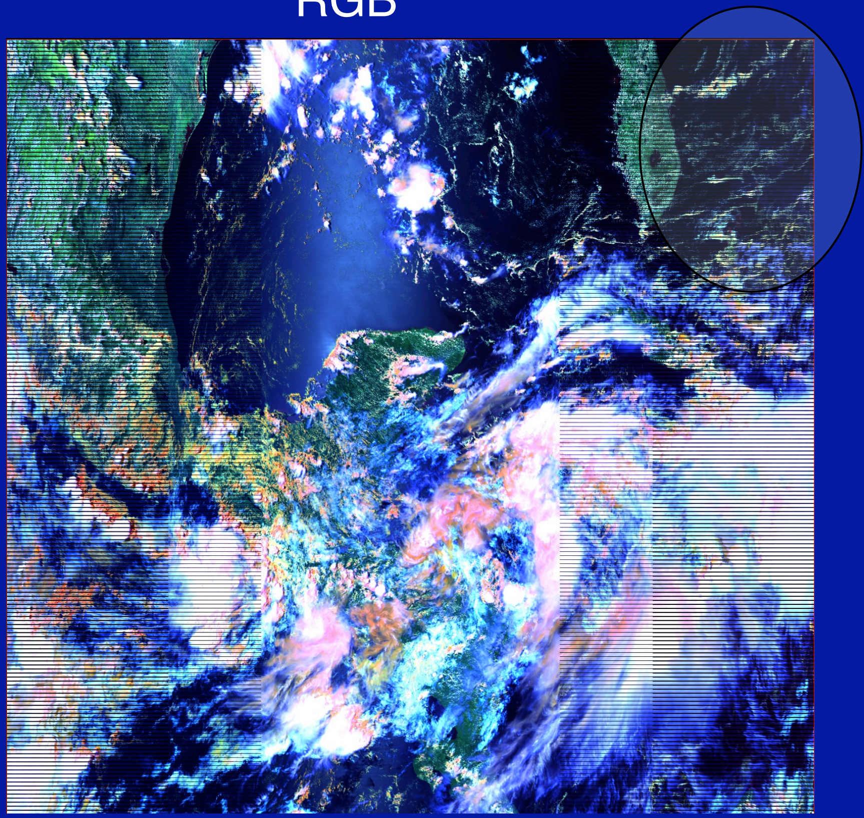
- Delivery of NPP Ed1 code in June 2013
    - Multilayer flags



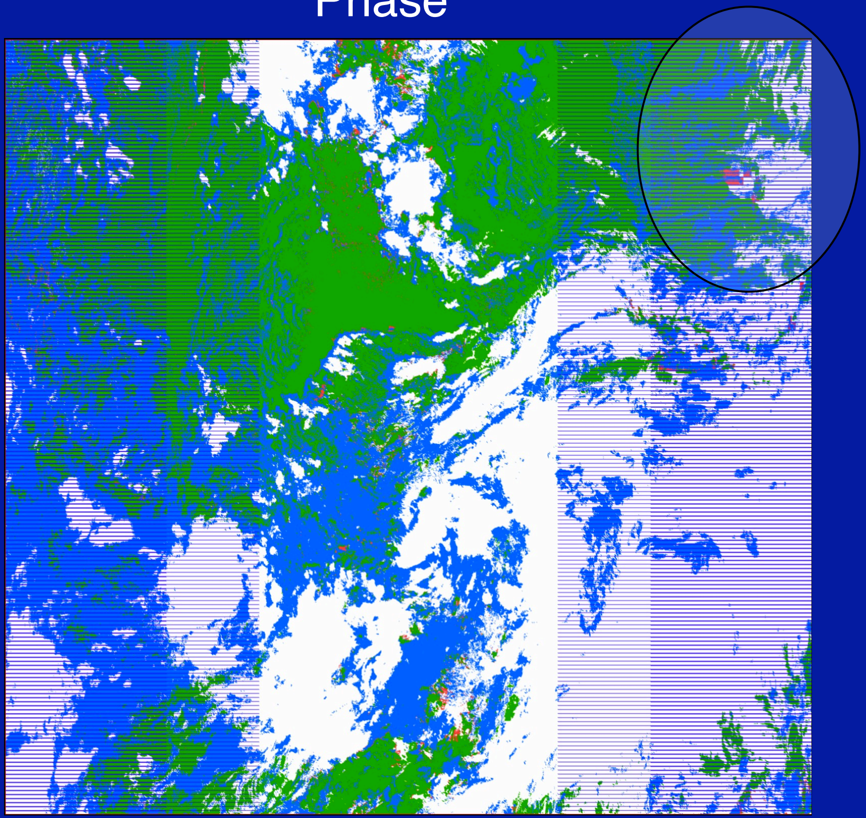
VIIRS Cloud Retrievals, 1900 UTC, 18 June 2012

Central America

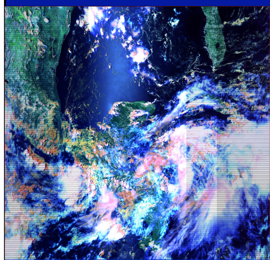
RGB



Phase



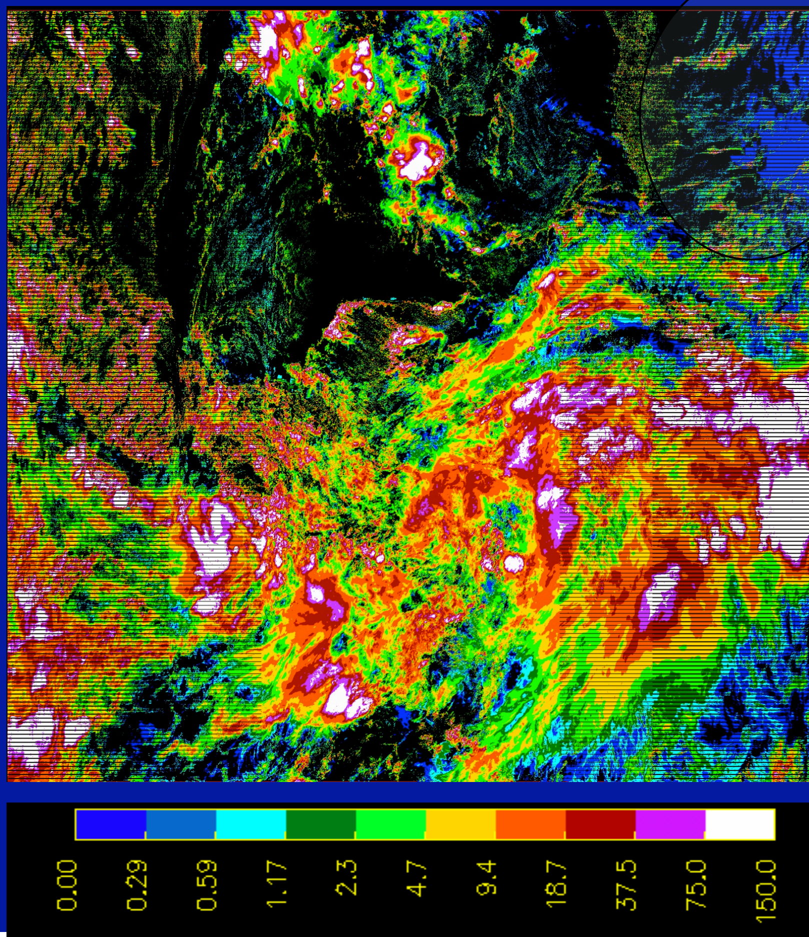
- Visually, mask and phase selection look very good
- Areas with invisible ice cloud cover => 1.38-μm detection of very thin clouds, COD < 0.2



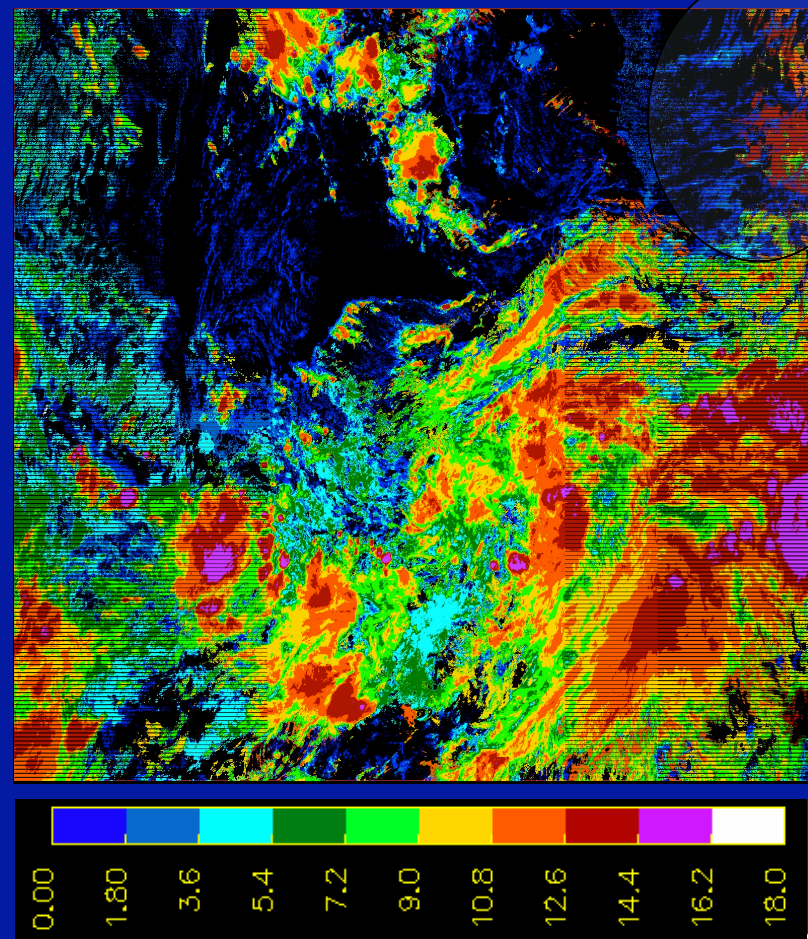
VIIRS Cloud Retrievals, 1900 UTC, 18 June 2012

Central America

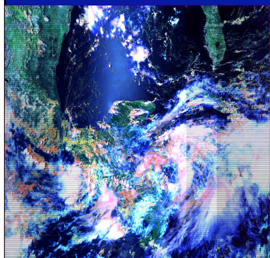
Optical Depth



Effective Height (km)



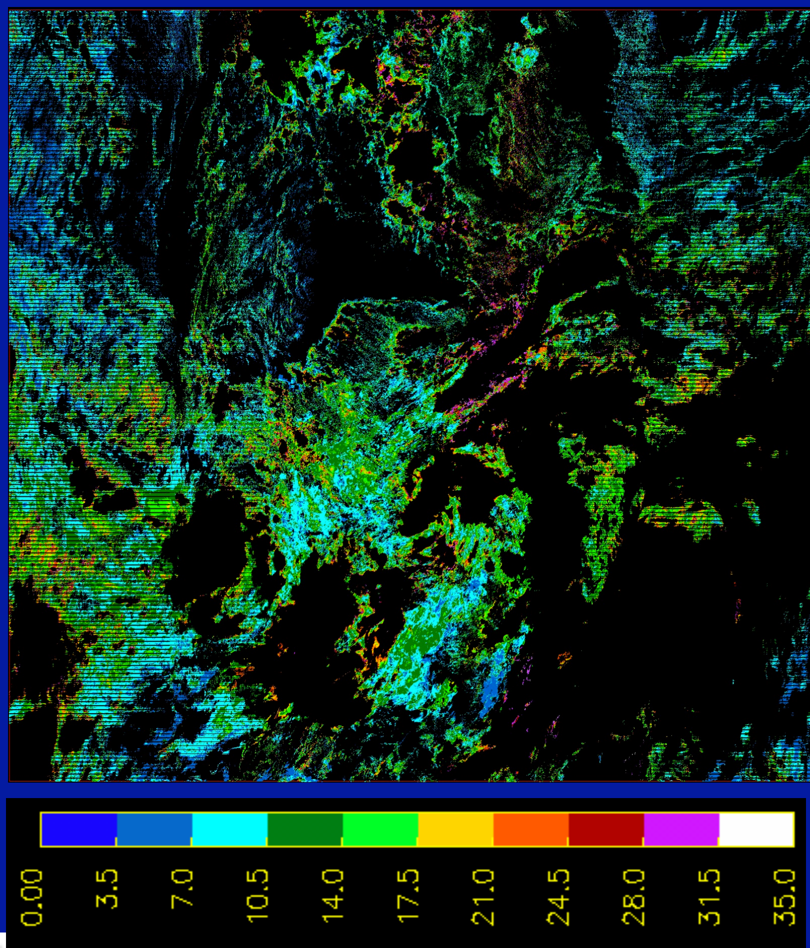
- Magnitudes of COD look right, heights also



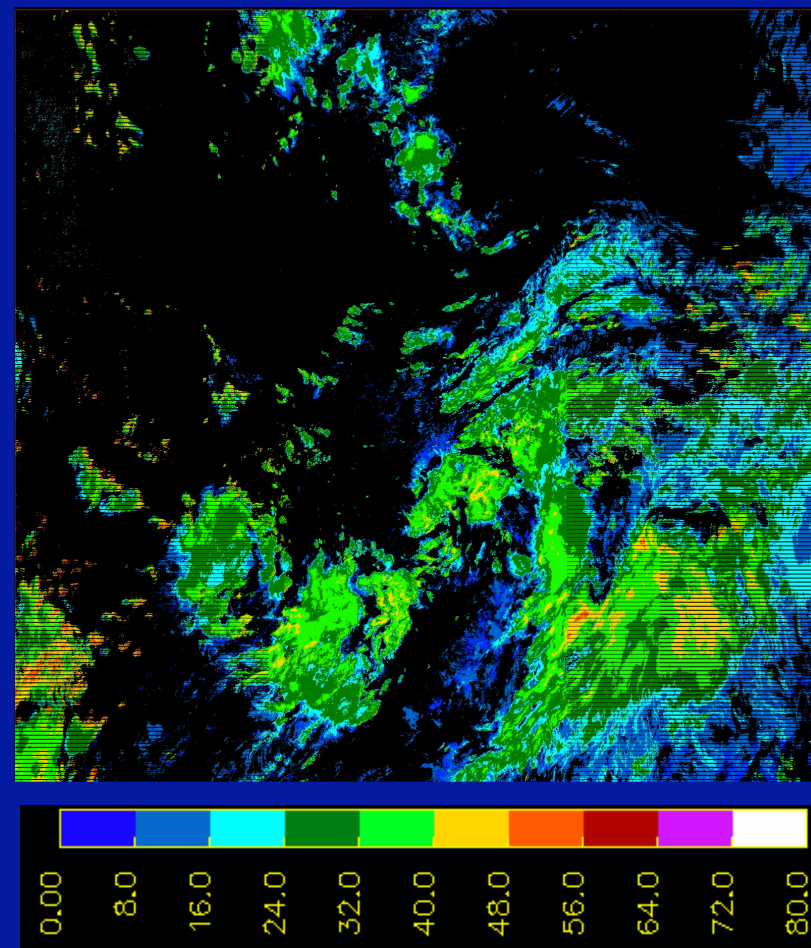
VIIRS Cloud Retrievals, 1900 UTC, 18 June 2012

Central America

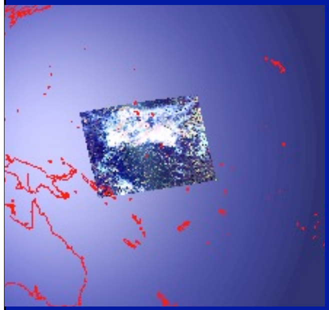
Water Re (μm)



Ice Re (μm)



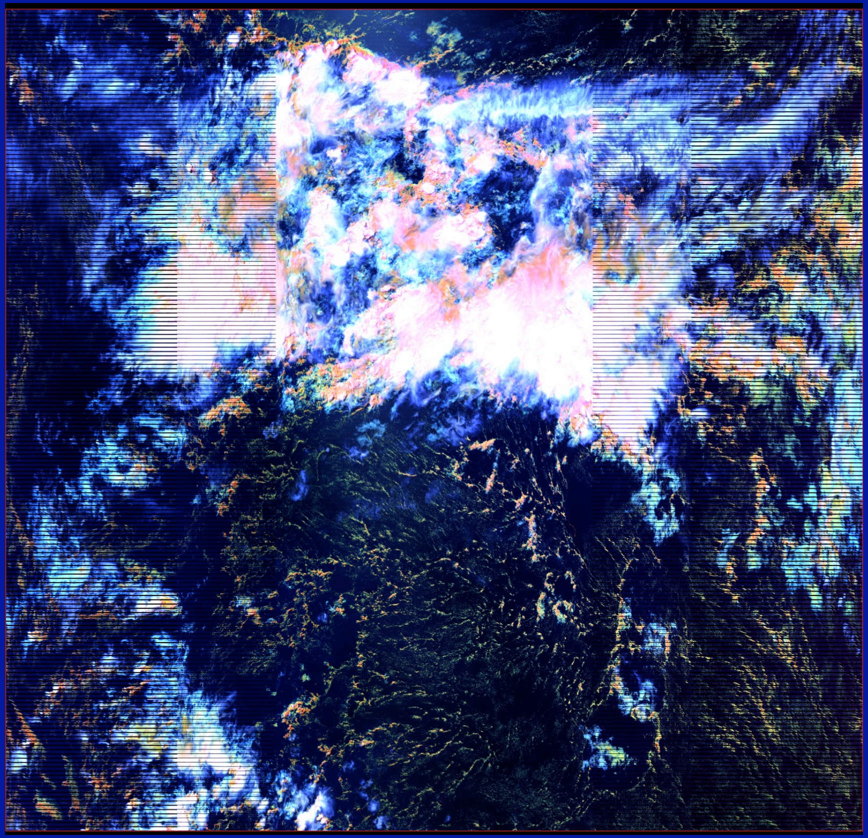
- Droplet sizes smaller than MODIS retrievals



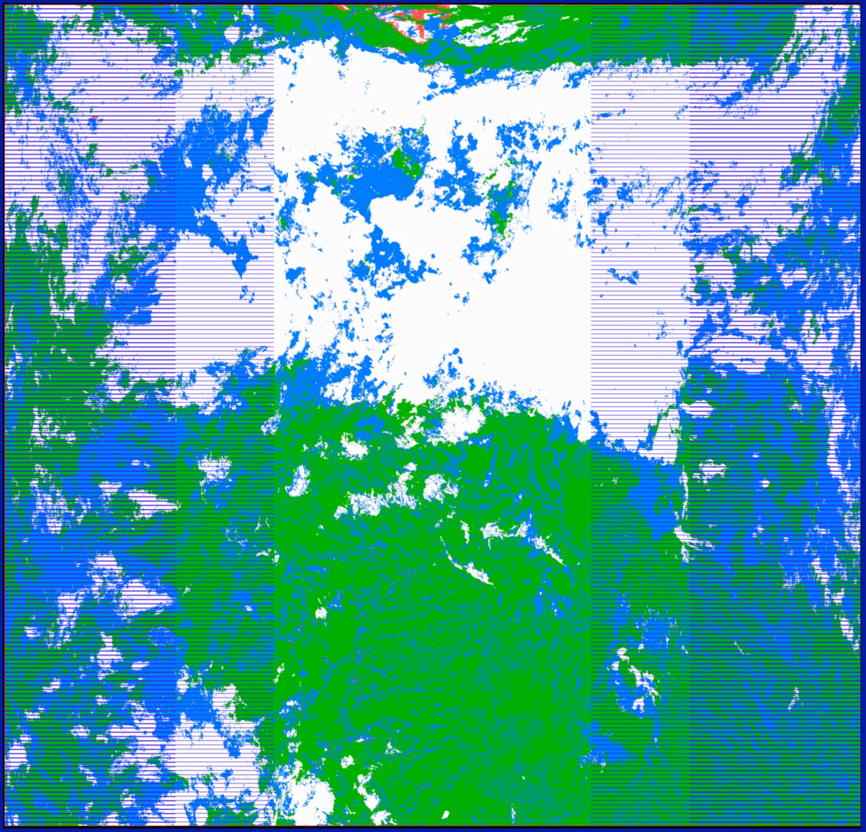
VIIRS Cloud Retrievals, 0200 UTC, 19 June 2012

TWP

RGB

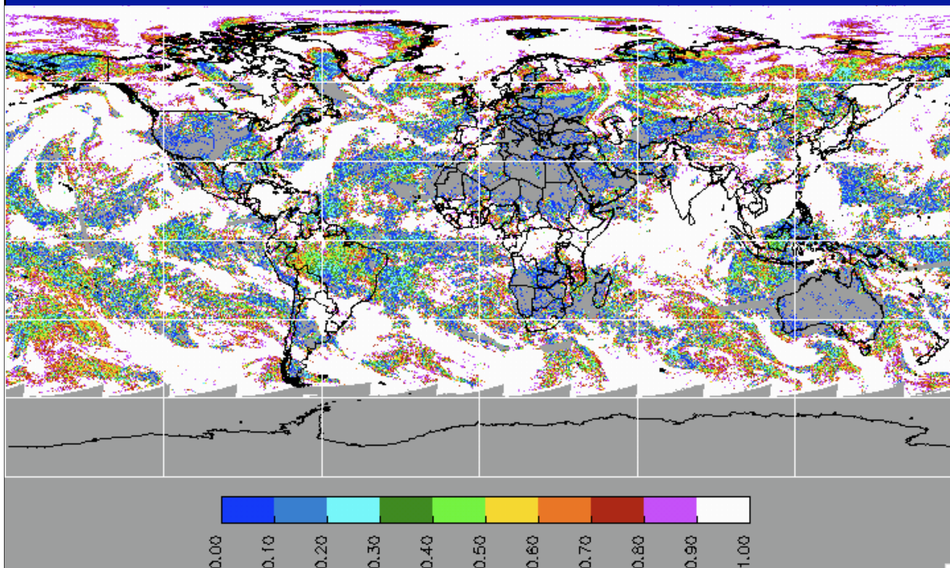


Phase

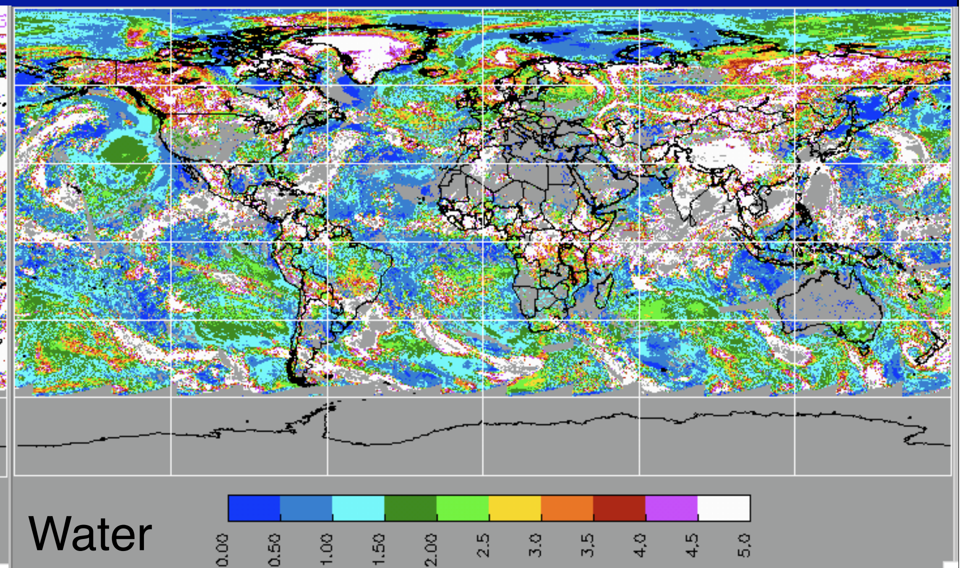


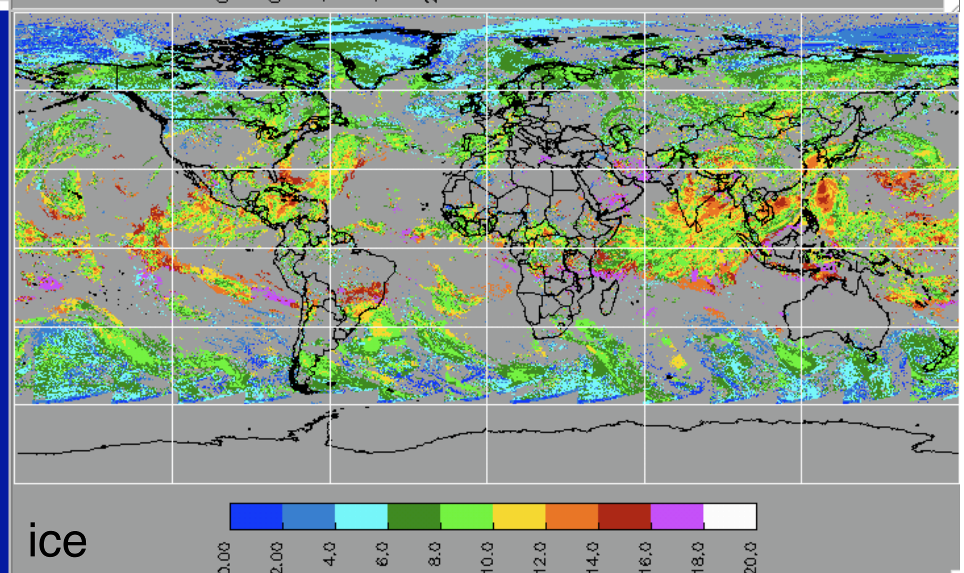
VIIRS Daytime Cloud Properties, 18 June 2012

Cloud Fraction



Effective Height, km

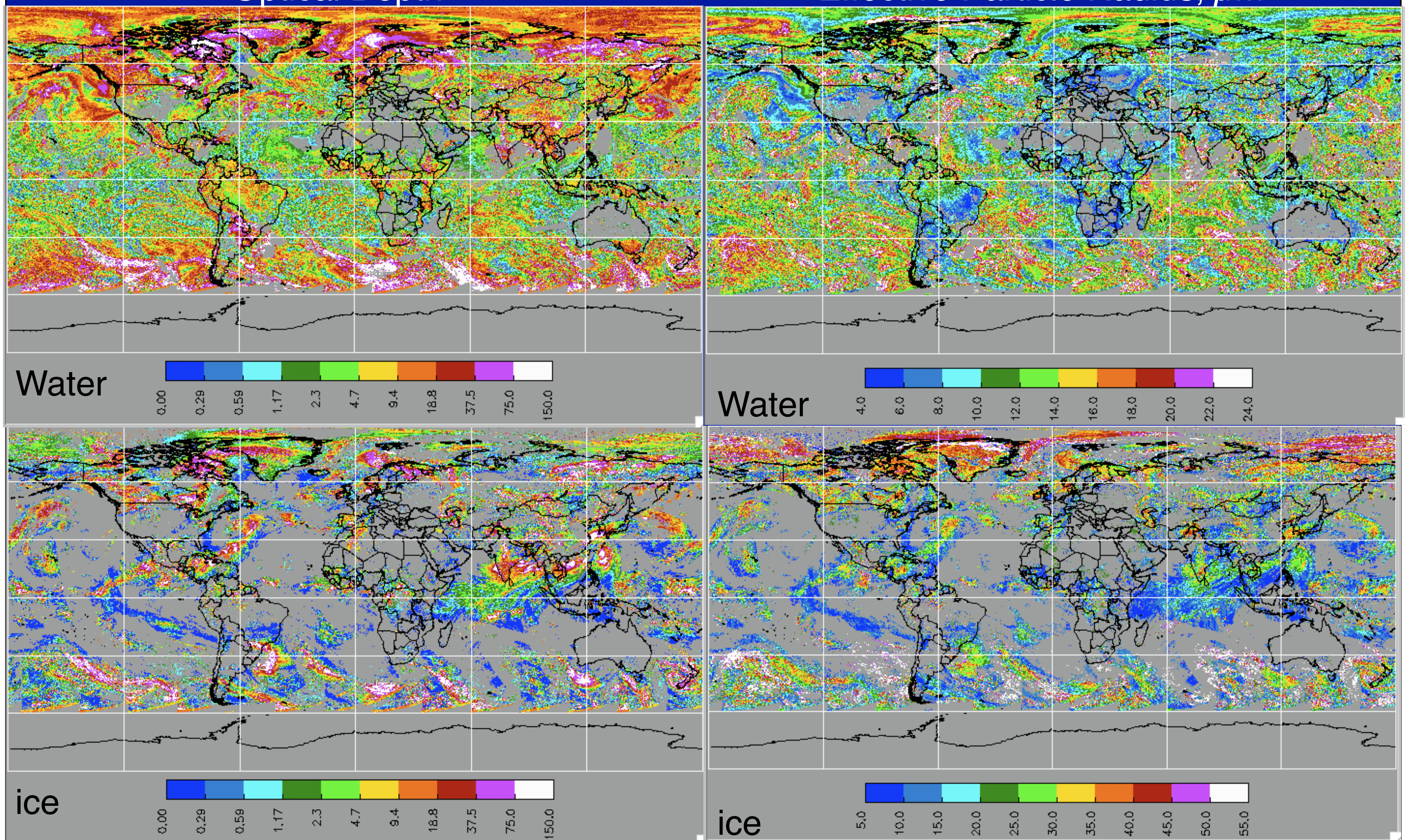




VIIRS Daytime Cloud Properties, 18 June 2012

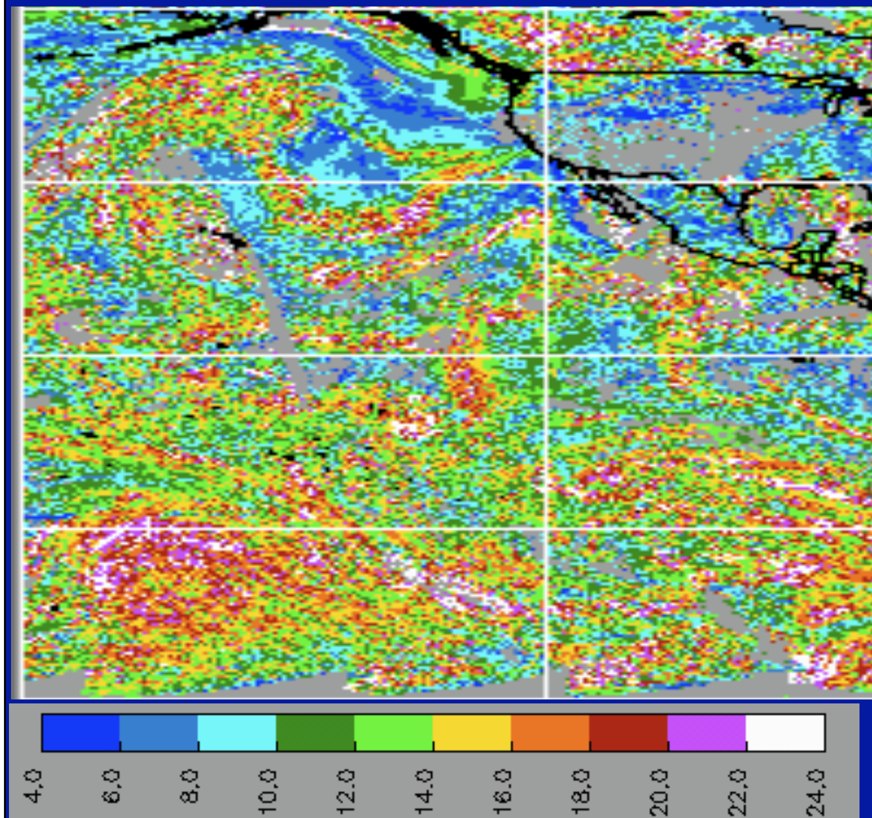
Optical Depth

Effective Particle Radius, μm

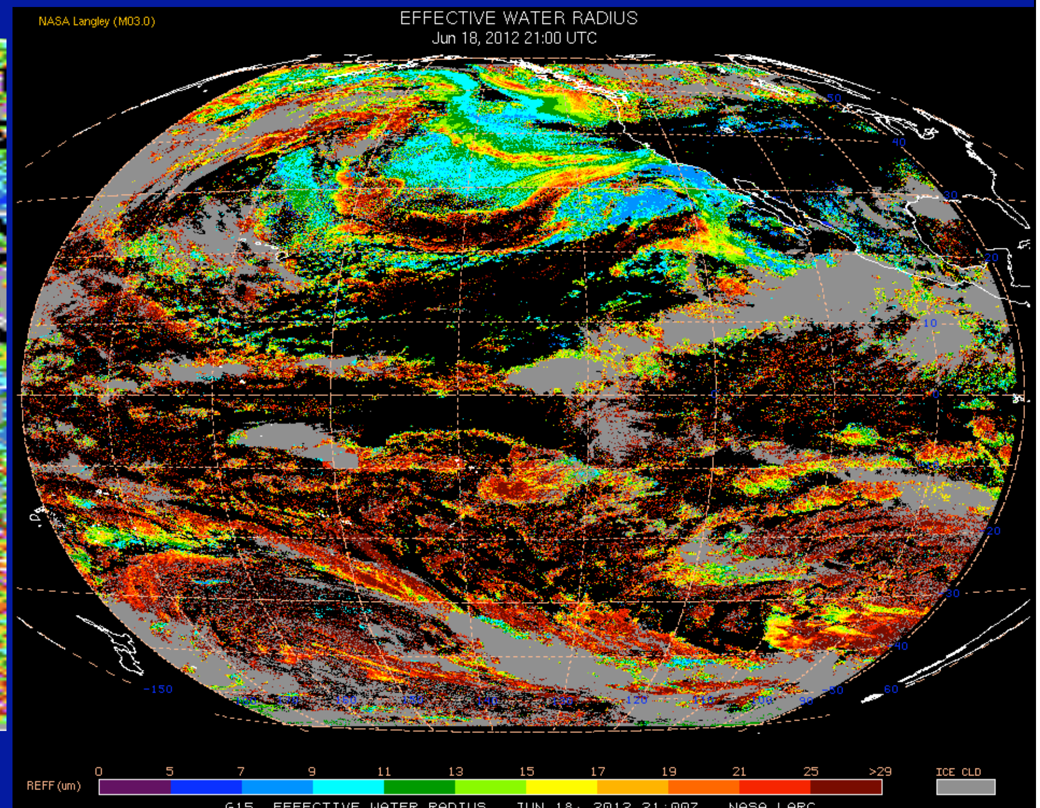


Effective droplet radius, 18 June 2012

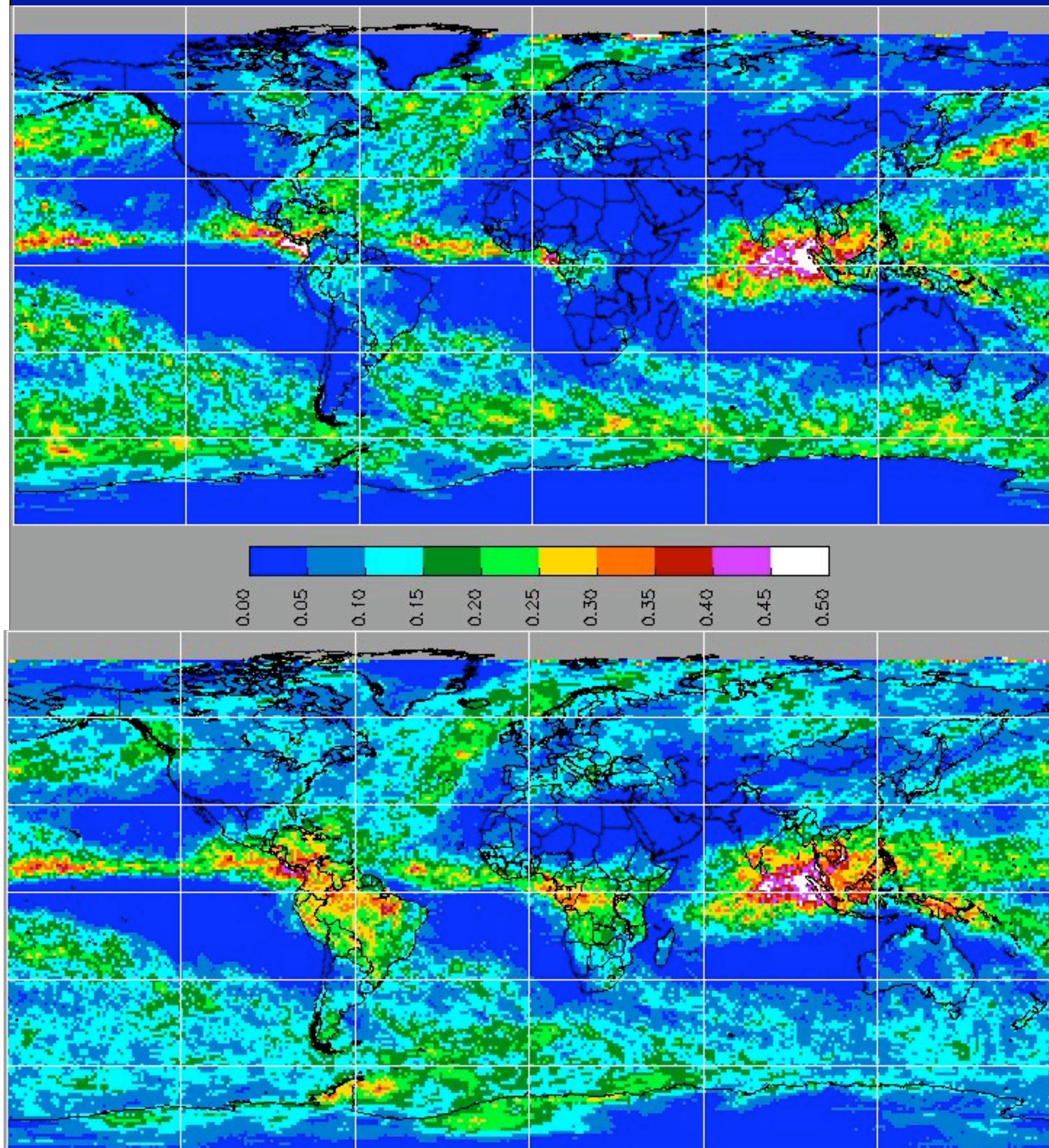
VIIRS, 18- 23 UTC



GOES-15, 21 UTC



- VIIRS Re patterns similar to GOES-15
- Re 2-4 μm smaller
  - current processing using MODIS parameters (e.g., Solcon)



Aqua Multilayer Cloud Fraction, October 2007

Ed 4, CO_2

- Lack of CO_2 channel on VIIRS precludes consistency with MODIS ML detection & retrieval

- 11-12 μm BTD method can be adjusted t be similar to CO_2 method

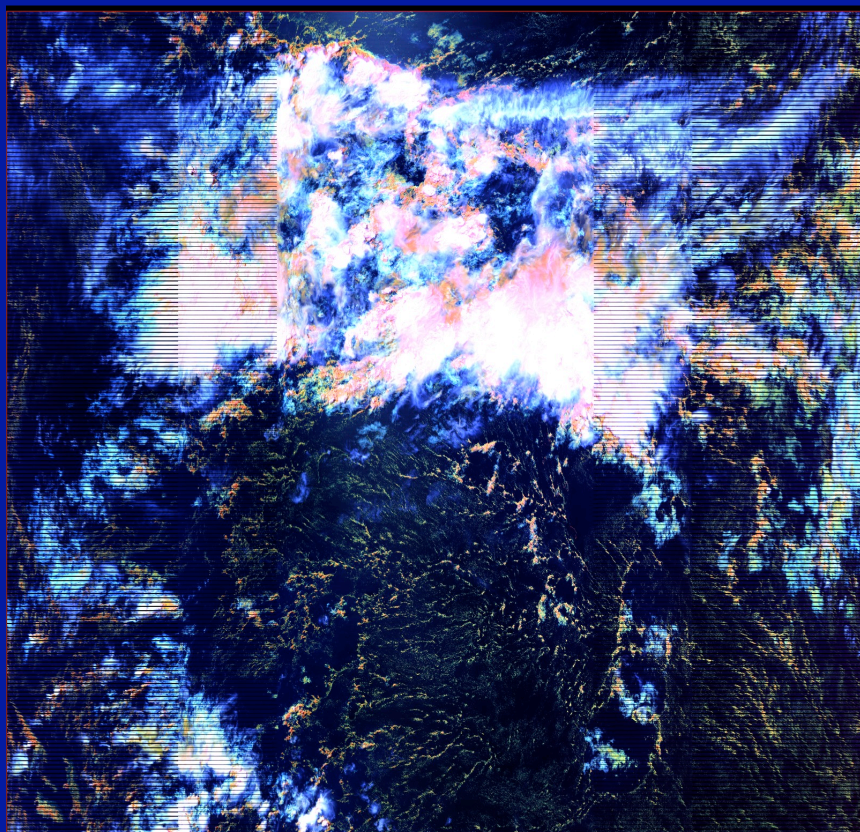
Ed 4, BTD

- no internally consistent retrieval approach developed yet for BTD technique

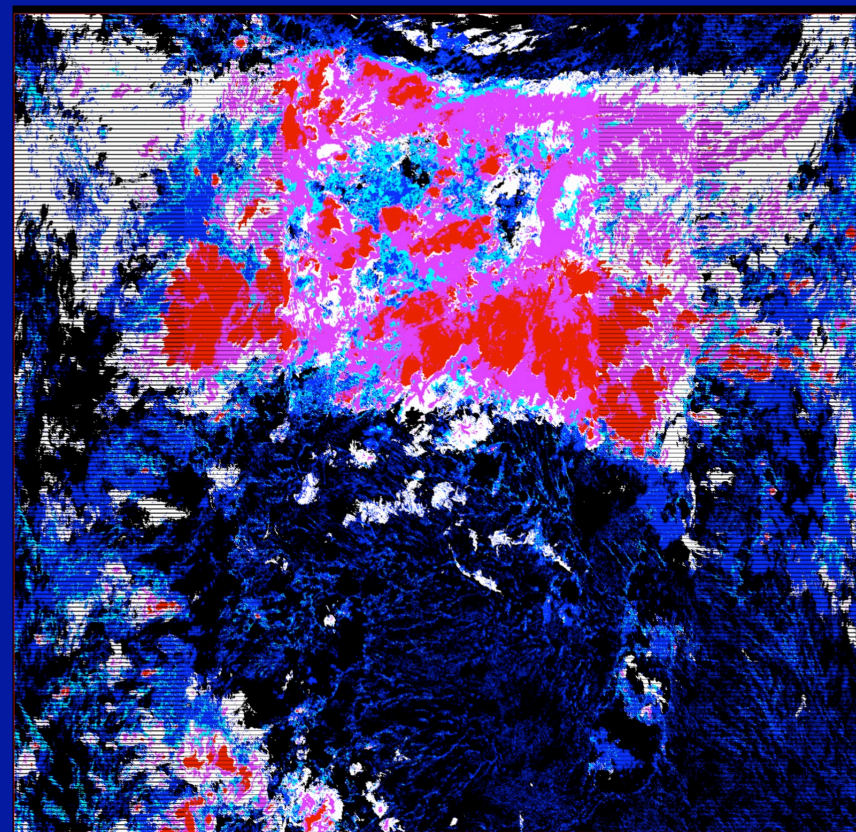
VIIRS Cloud Retrievals, 0200 UTC, 19 June 2012

TWP

RGB



BTD Classification

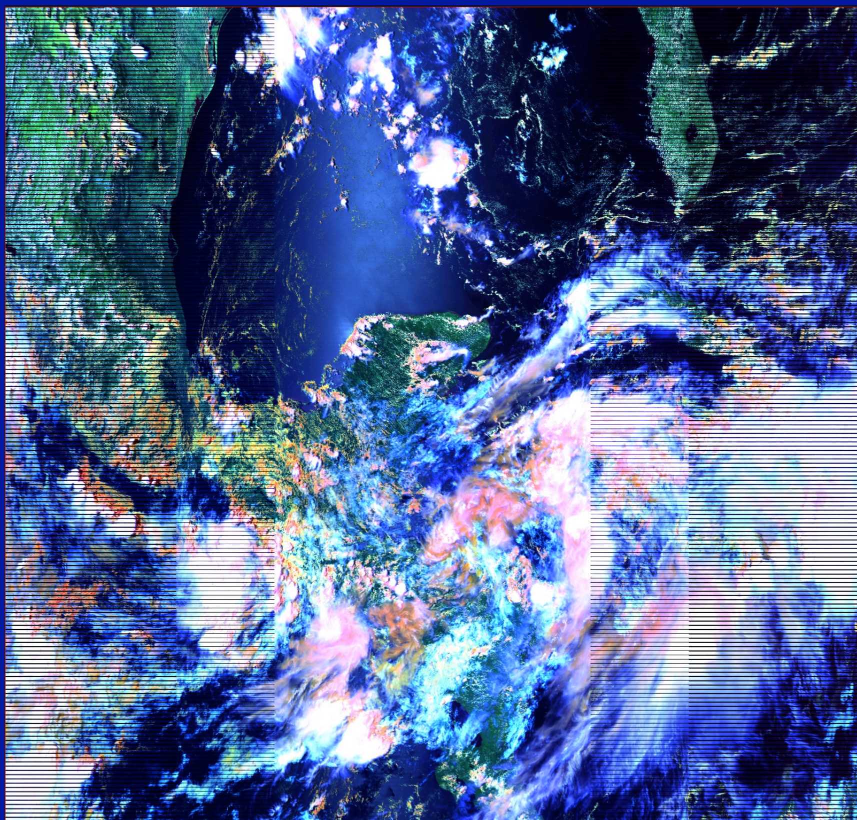


- Magenta & light blue indicate ML clouds
- Dark blue – SL water; White – SL ice; Re – thick ice

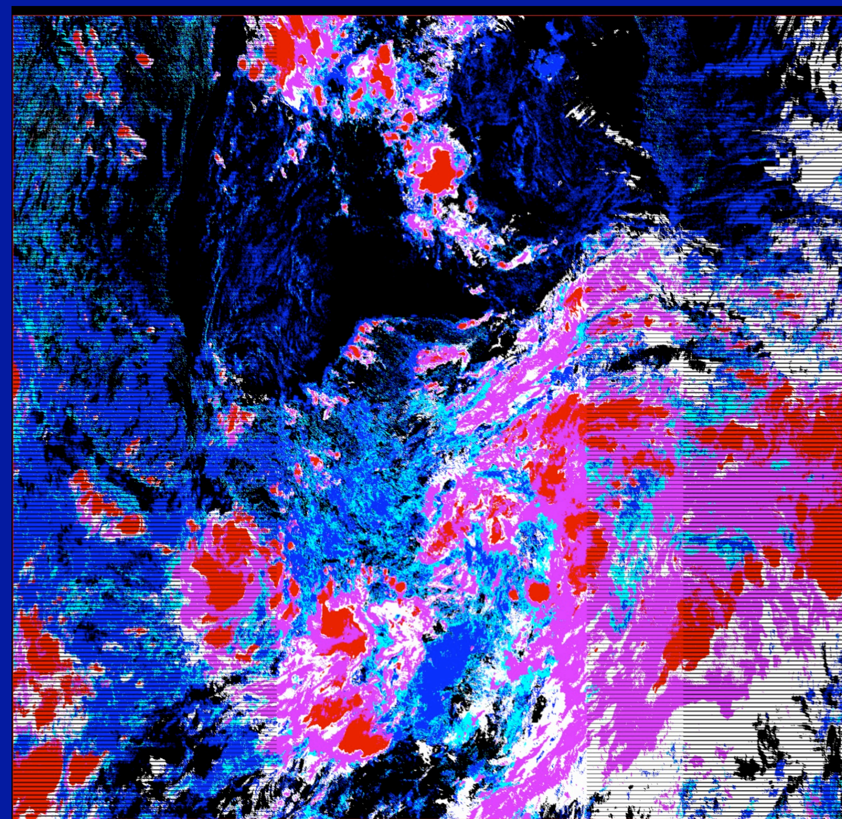
VIIRS Cloud Retrievals, 1900 UTC, 18 June 2012

Central America

RGB



BTD Classification



• Magenta & light blue indicate ML clouds

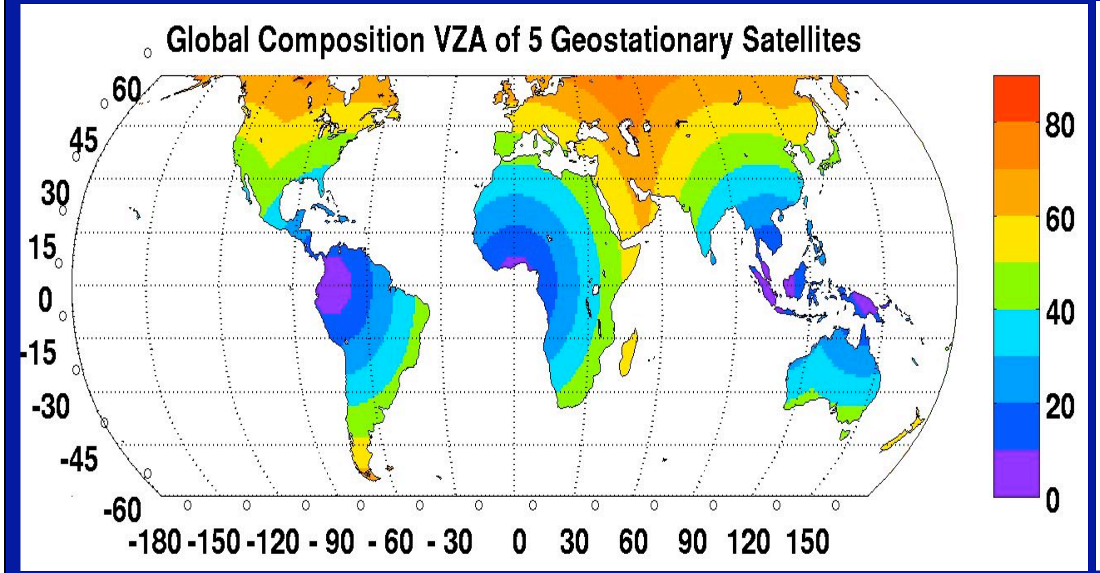
• Dark blue – SL water; White – SL ice; Re – thick ice

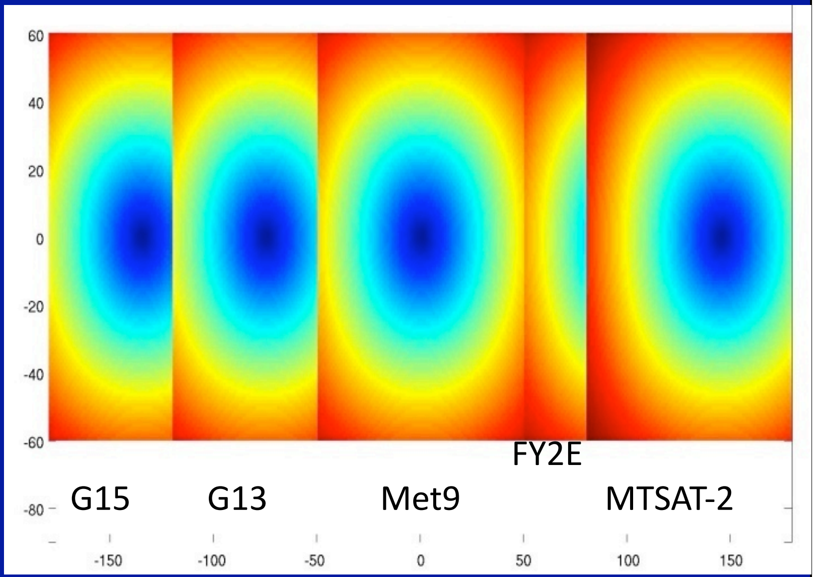
VIIRS Edition 1 Tasks

- Develop reader for new format
- Acquire necessary auxiliary information
  - *- corr-k coefficients (Kratz)*
  - *- solar constant*
  - *- reflectance/emittance models, if needed*
    - *- e.g., 2.25 μm instead of 2.13 μm*
- Tune cloud masks
  - *- use matched CALIPSO & Aqua data as guide*
  - *- polar night will need adjustments*
- Cross calibrate Aqua and VIIRS
- Develop QC and graphical software
- Perform independent validations
  - *- ARM sites*
  - *- other satellite data*
- Work on BTD multilayer code using MODIS
  - *- move to VIIRS*
- Deliver Ed1, June 2013

Hourly GEOSat Data for TISA

- Available geostationary satellites provide up to 1-hour global monitoring between ~60°S and ~60°N
- CERES Ed2 cloud retrieval algorithm (VISST/SIST) from MODIS adapted for geostationary satellite data processing





- FY-2 series will not be included in TISA analysis because of unreliability

  Meteosat-7 & 2-channel algorithm will be used for the gap

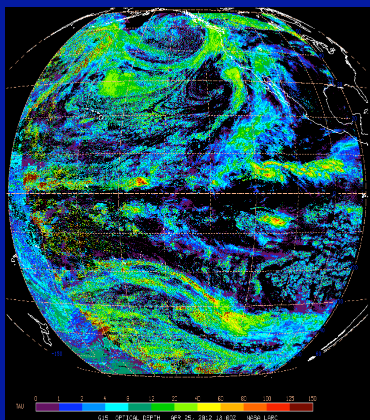
  - Currently running in near-real time, will process backward in time

    - GMAO working on assimilation of these data

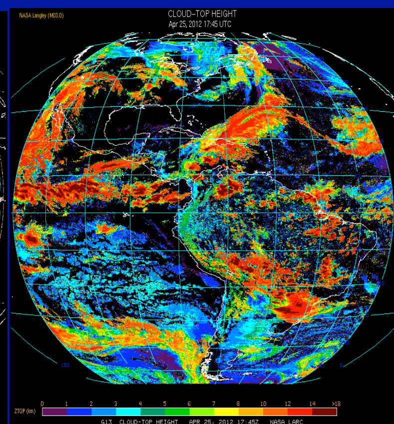
GLOBAL GEOSTATIONARY CLOUD PRODUCTS

18 UTC, 25 April 2012

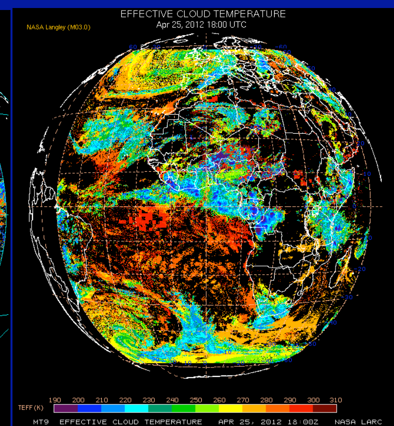
G15-TAU



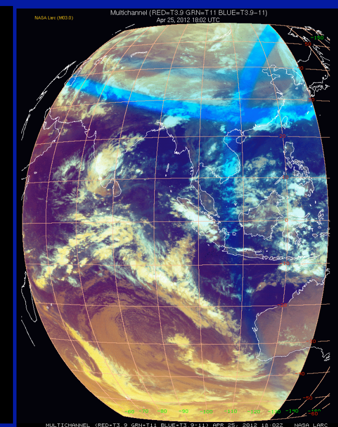
G13-ZTOP



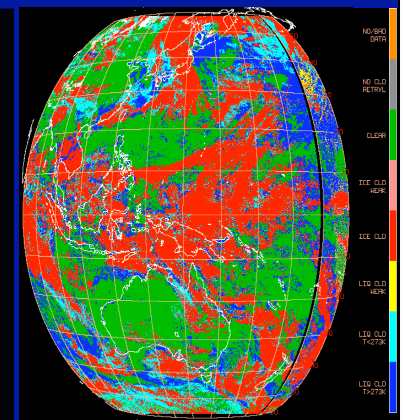
MET9-CTEMP

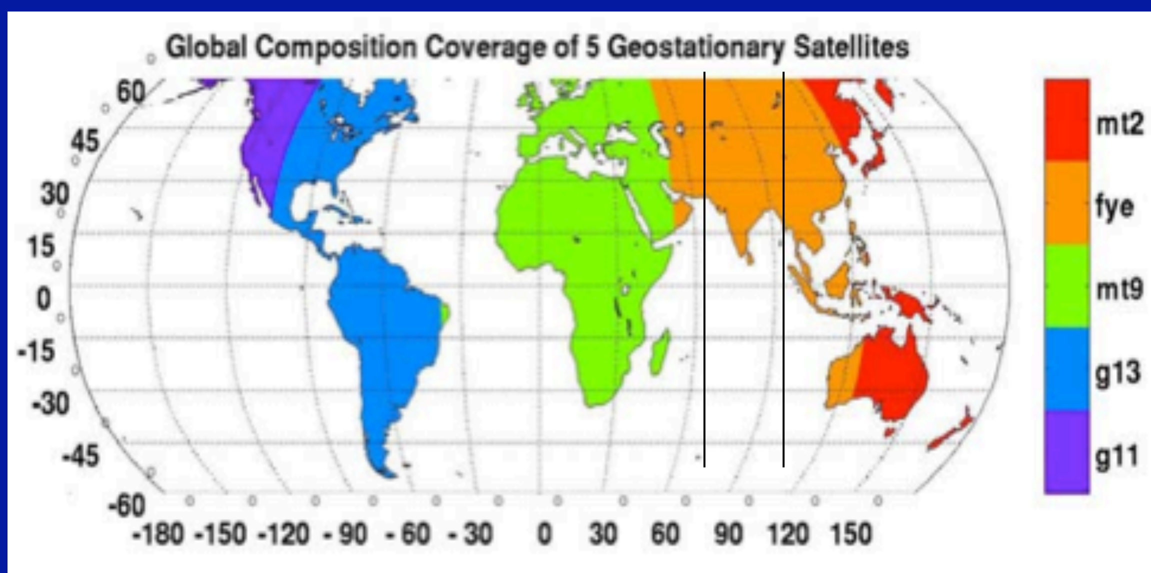


FY2E - RGB



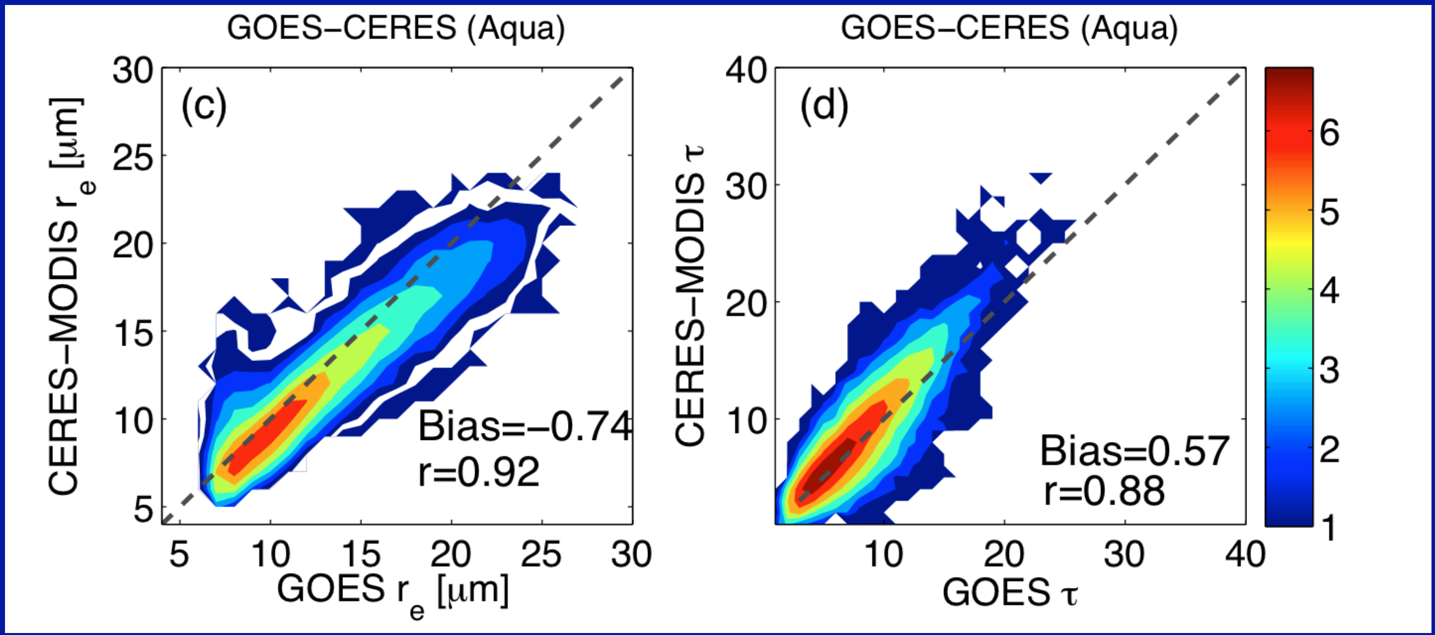
MTSAT- phase





Consistency of GOES & **CERES** Aqua Microphysics Retrievals
Marine Stratus, SE Pacific, Oct – Nov 2008

R_e Opt Depth

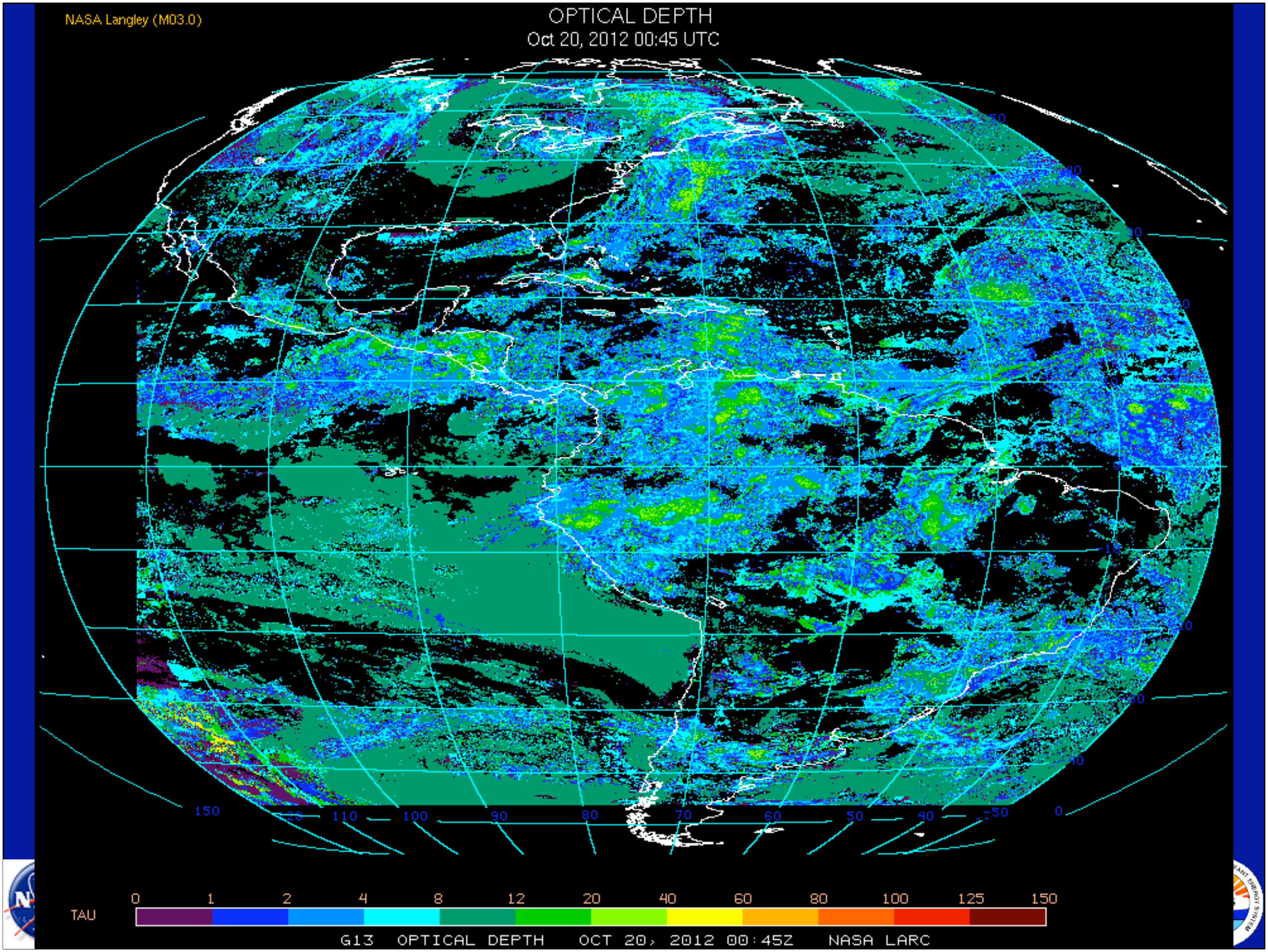


RMS = 1.5 μm (13%)

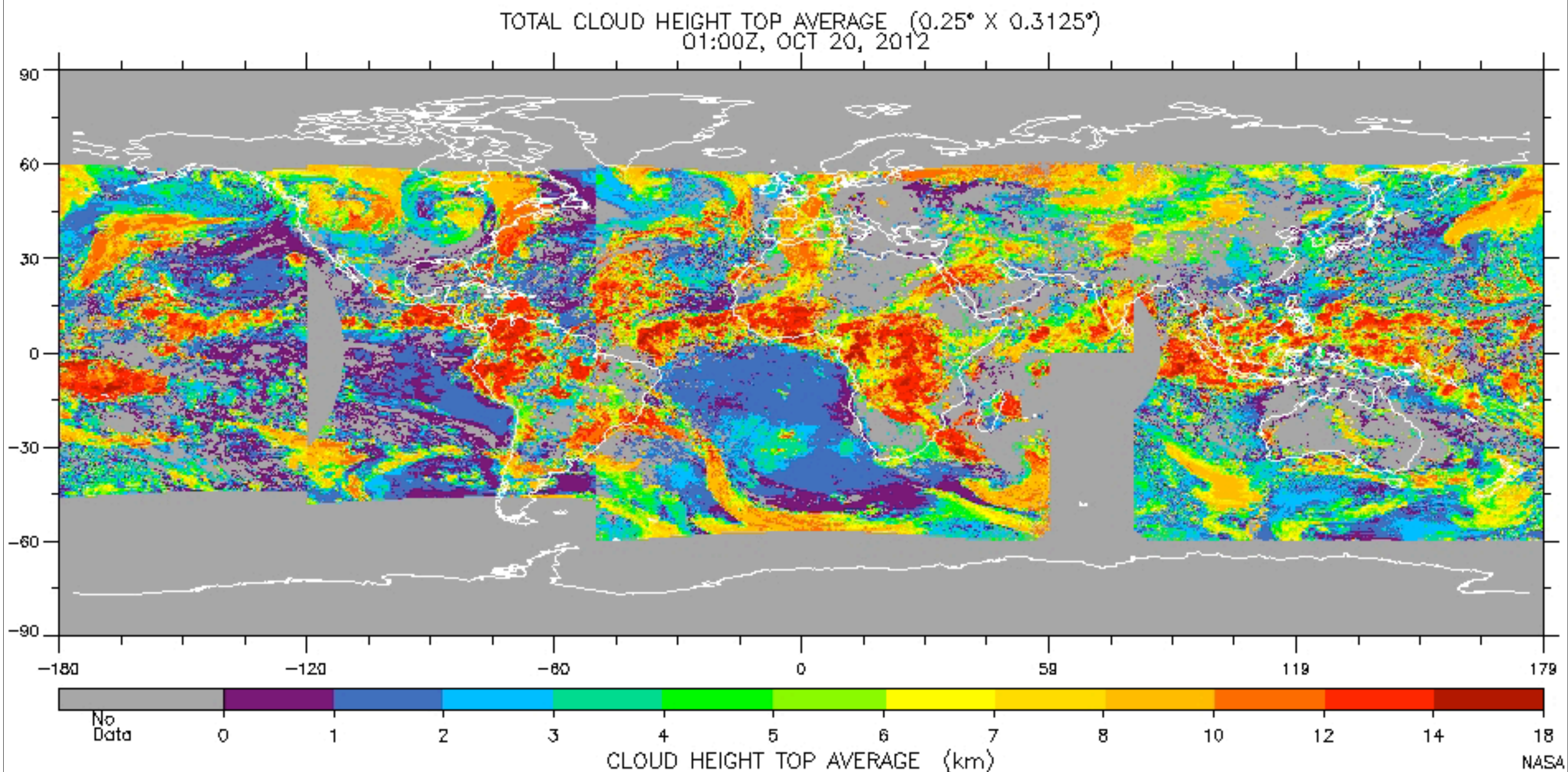
RMS = 1.9 (25%)

- Small differences in both droplet size and optical depth
- Optical depth differences at high end may be due to ozone differences

From *Painemal et al., JGR, 2012*


NASA Langley (M03.0)
OPTICAL DEPTH
Oct 20, 2012 00:45 UTC
TAU
0 1 2 4 8 12 20 40 60 80 100 125 150
G13 OPTICAL DEPTH OCT 20, 2012 00:45Z NASA LARC

GEOSat Hourly Cloud Height , 20 October 2012



- Testing in TISA has begun using Meteosat-9, January 2010 data
- Doelling will provide more detail

GEOSat Tasks

- Continue developing interface of datasets with TISA group

- Validate calibrations
  - *MTSAT especially*

- Tune cloud masks, if needed

- Test & implement nighttime thick ice cloud algorithm

- Develop fixes for twilight parameters
  - cloud amount not too bad, but other parameters (height)

- Iterate with ISA group to deliver products needed
  - revise algorithm when necessary

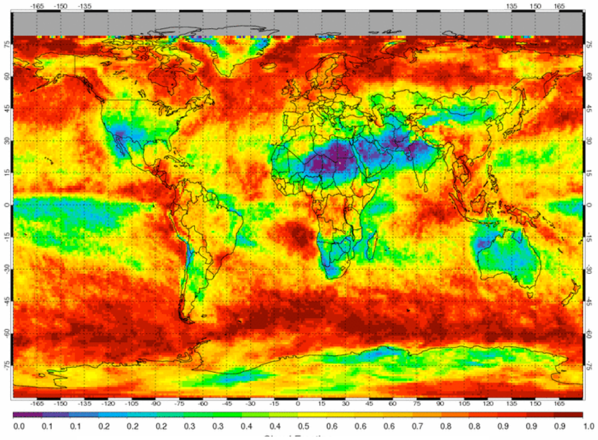
- Process gobs of data
  - need allocation of resources on AMIE & storage

CERES-Like AVHRR Clouds

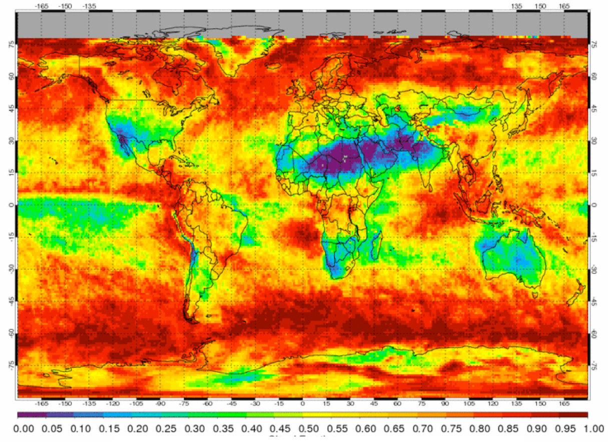
- NOAA CDR product as another record (+ISCCP & PATMOS-x)
  - allows a different take on clouds (1980 – MODIS era)
  - goal is consistency with CERES Terra & Aqua MODIS retrievals
  - subset used for reanalyzing ERBE data as a CERES-like product
    - *led by S. Kato*
  - CERES Ed 2-like algorithm
    - *only have 0.63, 0.87, 3.8, 11, & 12 μm data*
    - *includes Ed 4 embellishments*
    - *algorithm produces results in the middle of other retrievals*
      - *Stubenrauch et al. (BAMS, 2012)*
    - *includes skin temperature, overshooting tops*
  - uses calibrations linked to Aqua MODIS
    - *DCC, GEOSat, desert techniques*
  - potential for longer term climate studies
    - *input for reanalyses*
    - *cloud trends*
    - *skin temperature trends*

OCTOBER 2008 DAYTIME CLOUD FRACTION

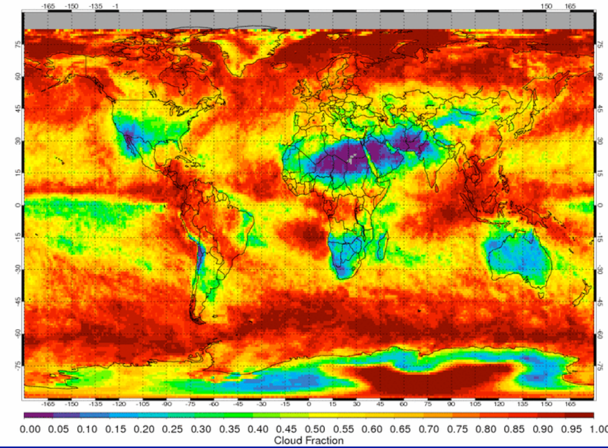
LaRC N18 AVHRR



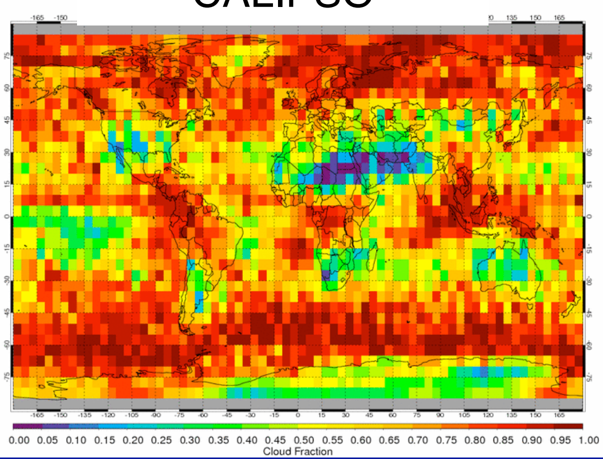
CERES Aqua



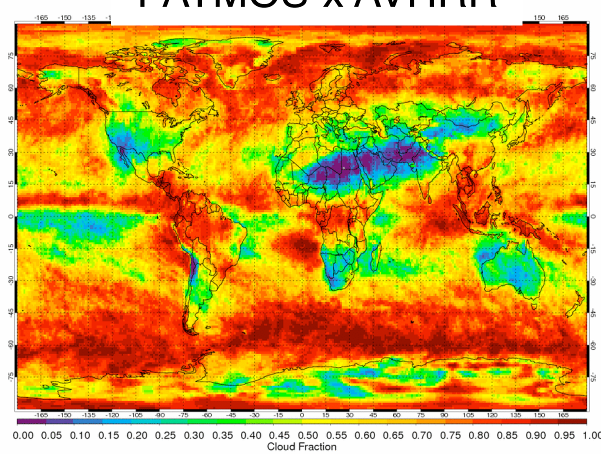
MODIS Team Aqua

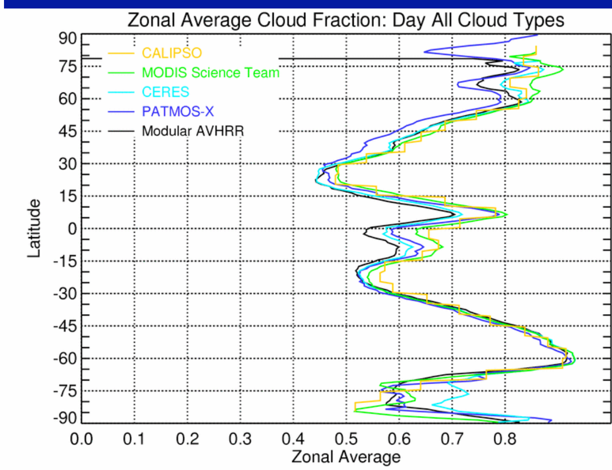


CALIPSO

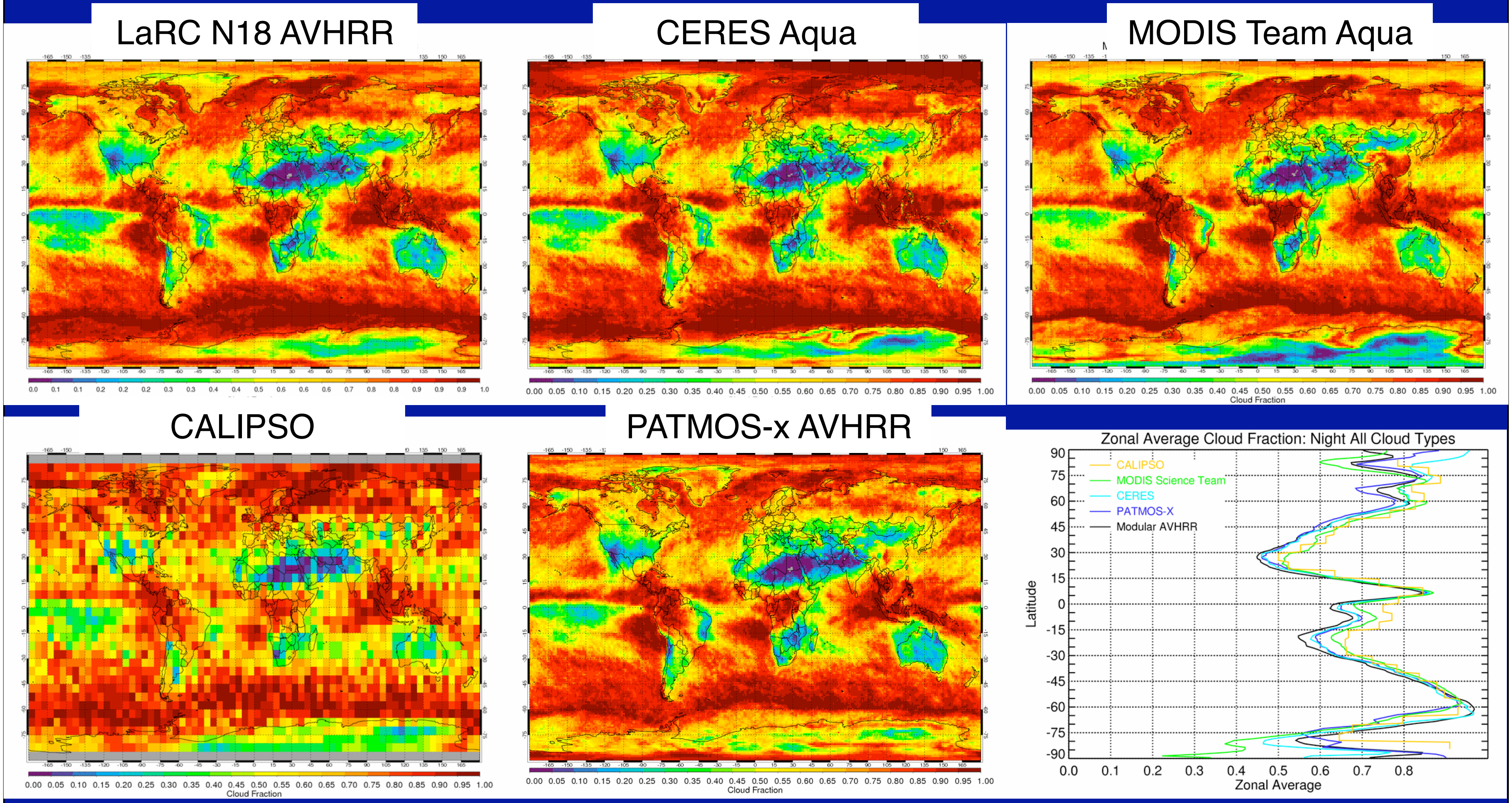


PATMOS-x AVHRR

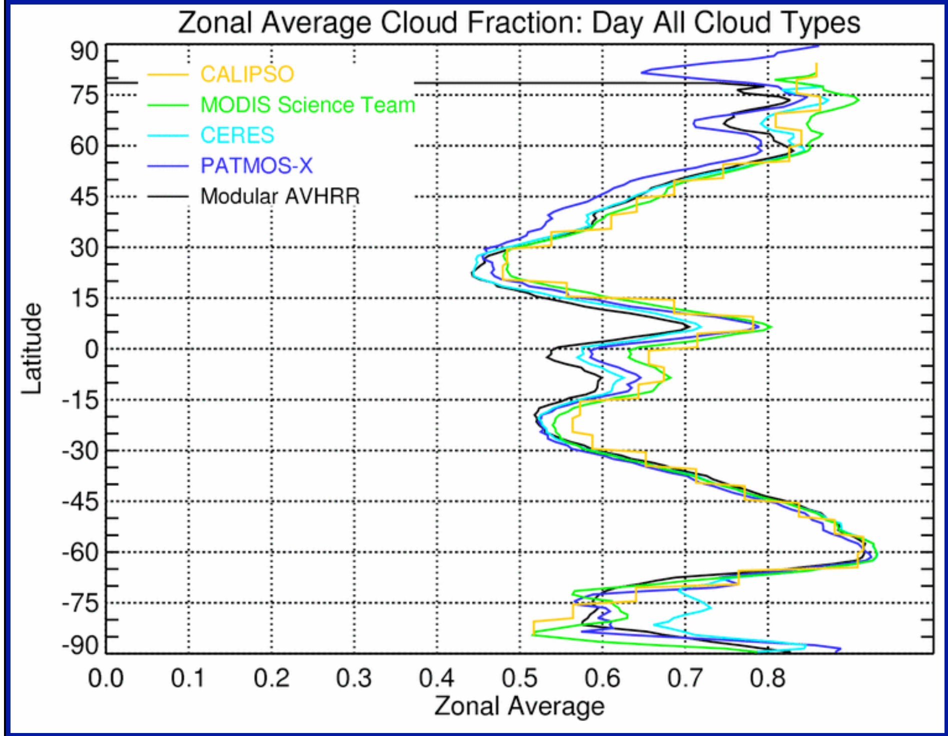


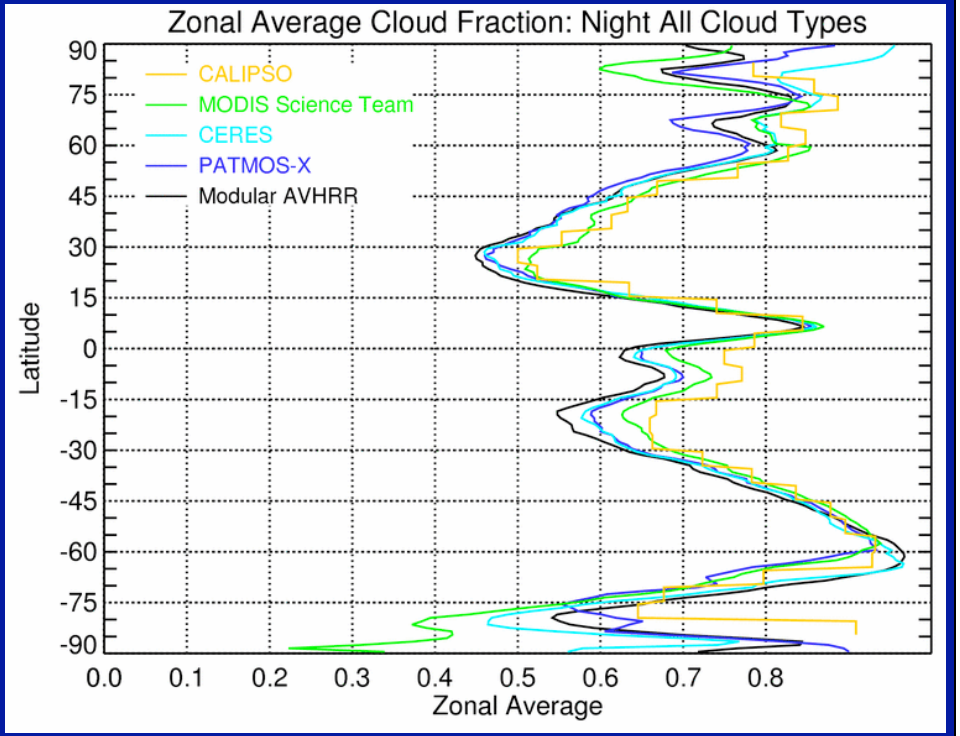


OCTOBER 2008 NIGHTTIME CLOUD FRACTION

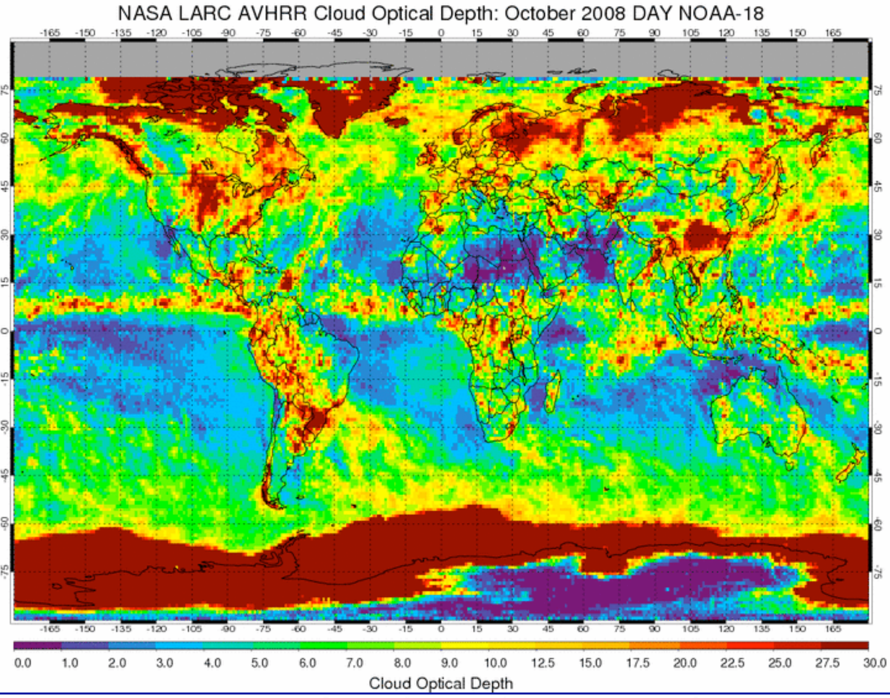


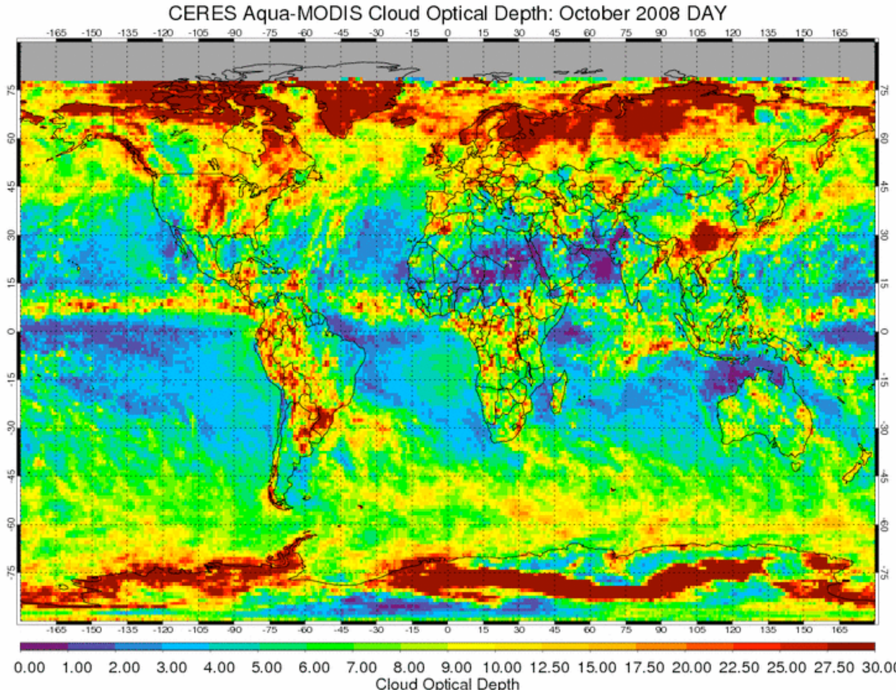
OCTOBER 2008 MEAN CLOUD FRACTION

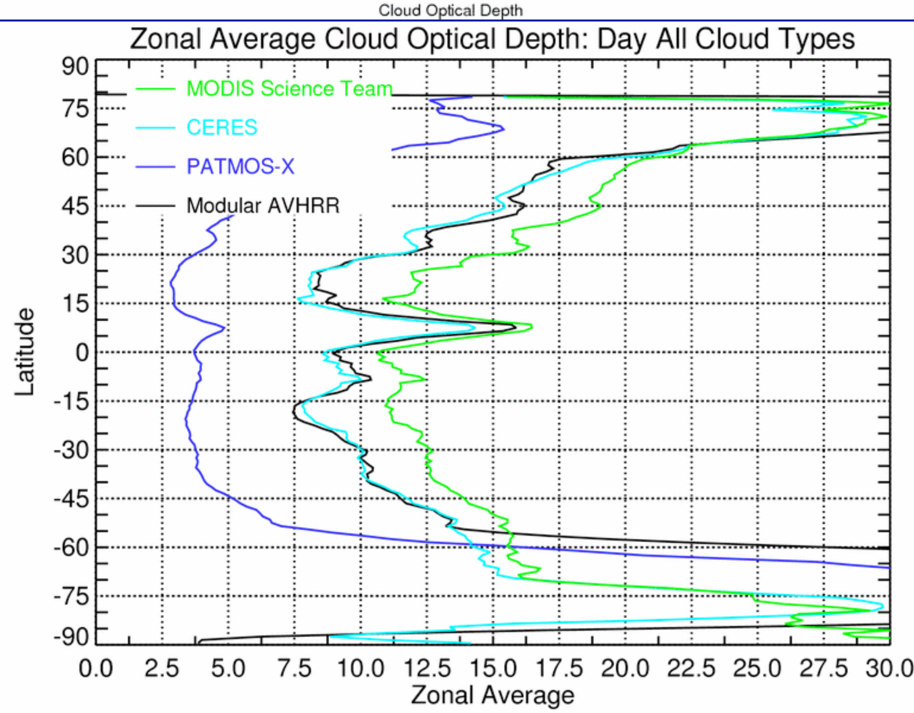




- CERES & LaRC AVHRR agree well in most zones
  - except Eq. & Antarc. (old Ed-4 used)
- PATMOS-x lowest during daytime
- Slight adjustments to be made before processing
- Data expected at end of 2013







OCTOBER 2008 Day Cloud Optical Depth

- Patterns match very well
  - except over snow
- Zonal means very close
  - except over snow
- Need better way to estimate COD over snow without 1.24-μm channel

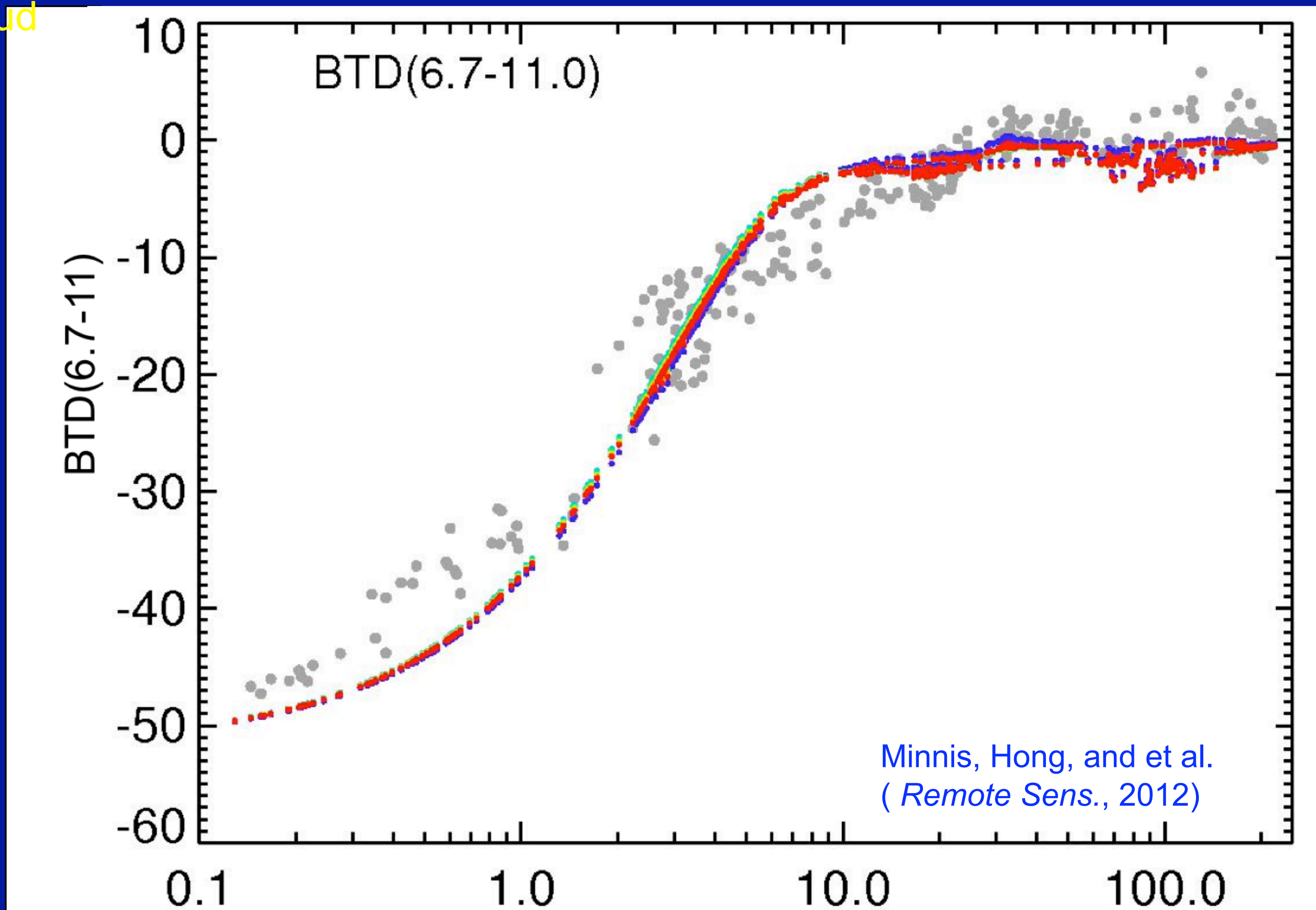
Other Challenges Ahead

E.g., improving characterization of clouds at night

- start with ice clouds
- then on to water

Non-opaque Ice Cloud Optical Thickness from 6.7 and 11.0 µm

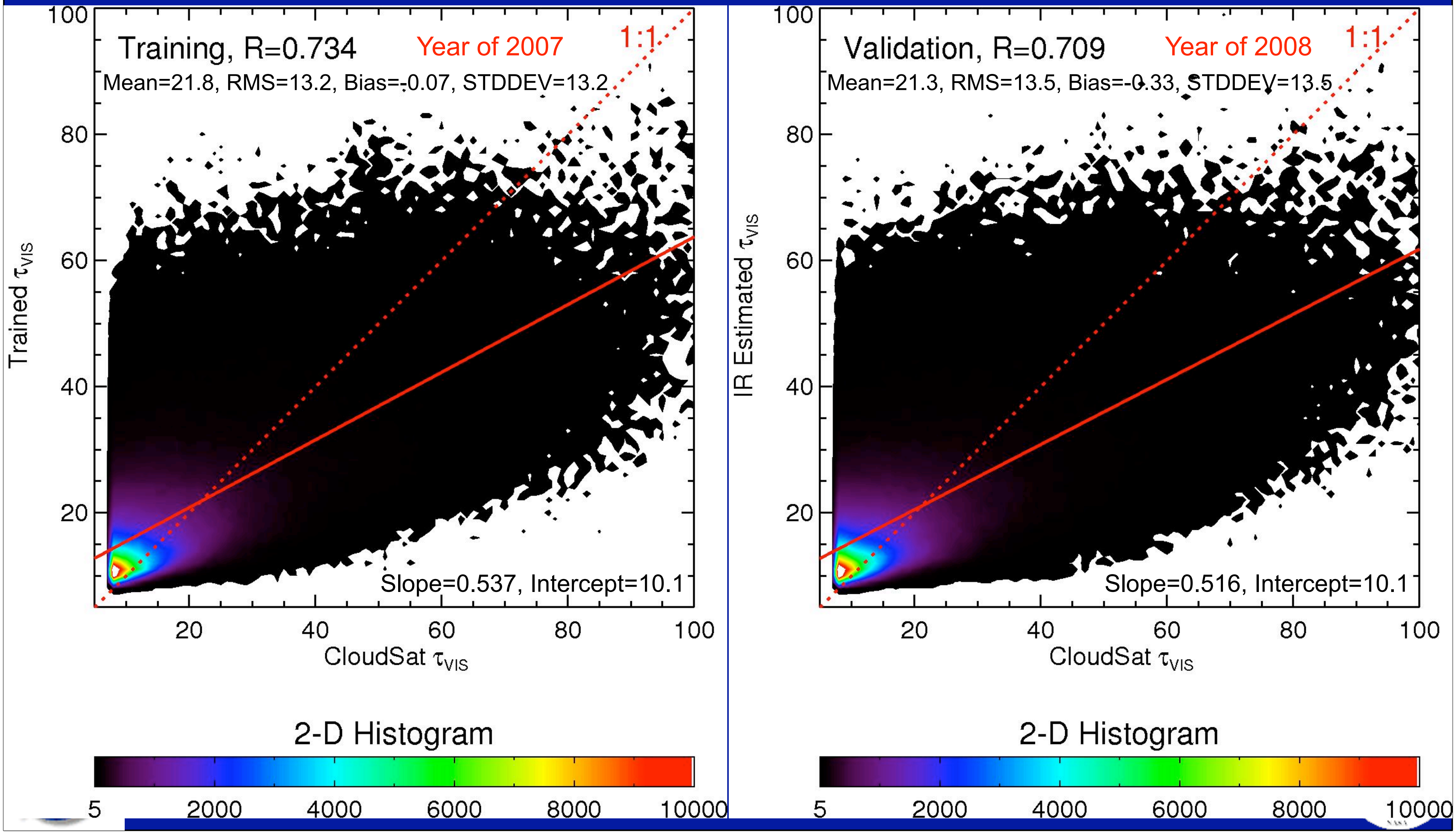
Using BTD(6.7-11.0) for Tau, weakly sensitive to Re
- comparison of simulation and observations over deep convective cloud



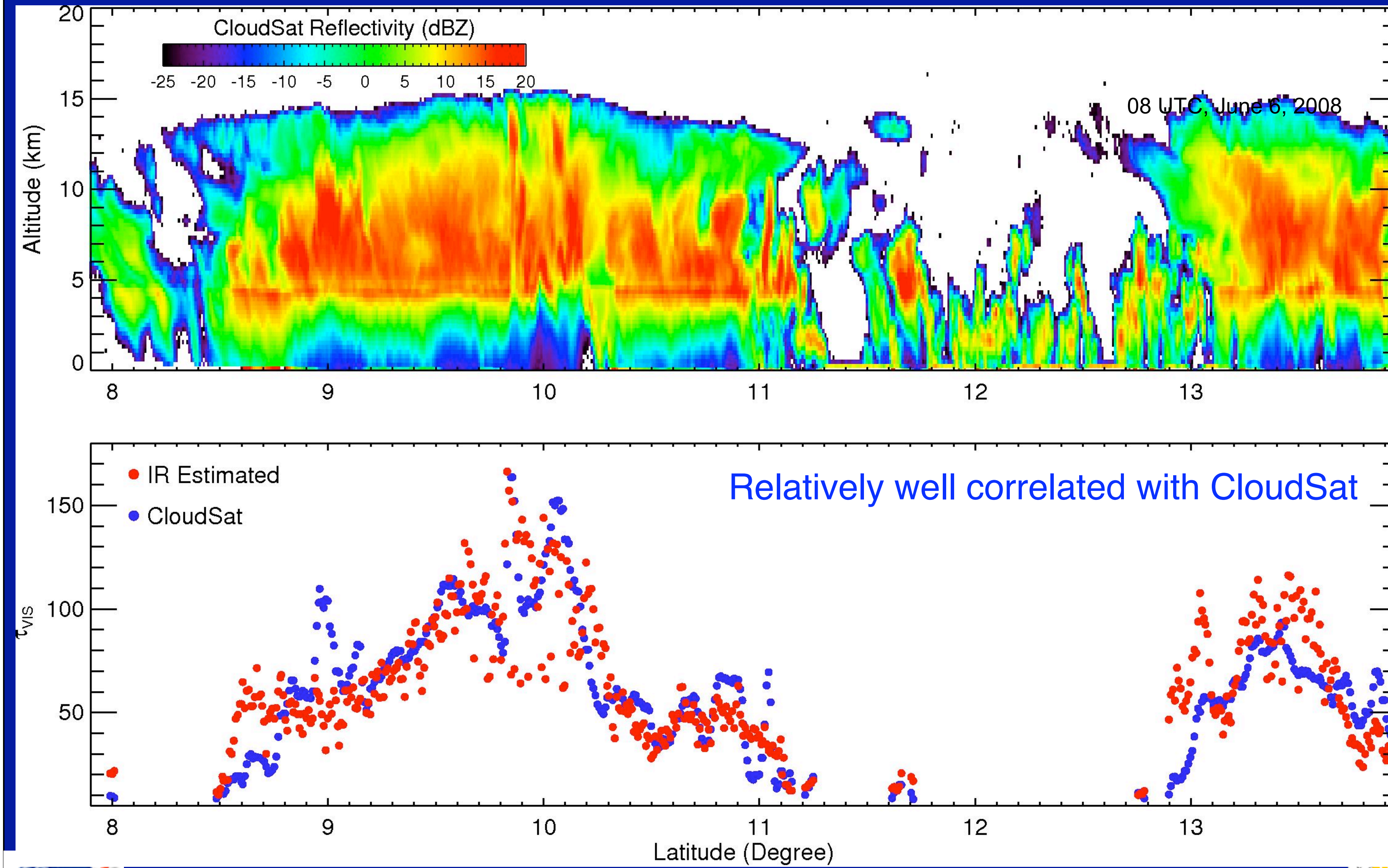
Estimating Thick Ice Cloud COD at Night

- Use neural net approach

Training data: 2007 LaRC C3M Data at night (globally) *(Kato et al., 2011)*
Validation data: 2008 LaRC C3M Data at night (globally)



Opaque Ice Cloud Optical Thickness from IR Measurements: An Example of Application



- Hong et al., IRS, 2012

Geographical Distribution of Opaque Ice Cloud Optical Thickness at Nighttime